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Anderson-Nichols and Co., Inc., Palo Alto, CA

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FOREWORD

As environmental controls become more costly to implement and the penalties of judgment errors become more severe, environmental quality management requires more efficient analytical tools based on a greater knowledge of the environmental phenomena to be managed. As part of this Laboratory's research on the occurrence, movement, transformation, impact, and control of environmental contaminants, the Technology Development and Applications Branch develops management or engineering tools to help pollution control officials achieve water quality goals through watershed management.

As concern about potential contamination of groundwater has increased, efforts to evaluate the use of a pesticide in a given agricultural situation have become more important. These evaluations to identify significant environmental risk have involved both model simulations and field or plot studies. To augment field or modeling studies, a screening technique was developed by which agricultural chemicals can be evaluated to determine whether they will move in significant quantities past the crop root zone. The procedure accommodates a wide range of basic pesticide properties, soils, and crops. The leaching evaluation technique is quickly and easily used and requires minimal background and training on the part of its users.

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ABSTRACT

A methodology has been developed to assess potential pesticide leaching from the crop root zones in major (corn, soybean, wheat and cotton) crop growing areas of the United States. Use of the Leaching Evaluation of Agricultural Chemicals (LEACH) methodology provides an indication of the presence or absence of leaching past the rooting depth and, if such leaching is indicated, its severity. LEACH was developed through the use of long term simulation (i.e., 25 years) of annual pesticide leaching time series using the Pesticide Root Zone Model. The user must evaluate key parameters for a pesticide-site-crop-management scenario to locate pesticide leaching cumulative frequency distributions. Each scenario has a unique distribution associated with it. The distribution functions indicate the chance that the annual quantity of pesticide leached past the crop rooting depth will exceed a given value. The distributions can be used as an integral part of a framework for decisions concerning the use of the pesticide.

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SECTION I

INTRODUCTION

The growing threat to ground-water supplies from chemicals introduced into the environment is an issue of national concern. This concern is reflected by the current proposed guidelines for the registration of pesticides (U.S. EPA, 1978), which requires that a pesticide's mobility in soils be established. The potential for a pesticide to leach through the soil profile can indeed be measured in laboratory or column studies. In general, however, such studies can only establish the tendency for a compound to leach relative to a reference compound/soil combination. Determination of whether the compound will actually leach significantly under field conditions requires quite a different approach.

The movement of a pesticide through the soil in an agricultural application is a function of soil physical and chemical properties, pesticide properties, local watershed and meteorological conditions, and, additionally, soil, water and pesticide management variables. Field or plot studies unfortunately require a great deal of time and expense to answer the important questions concerning pesticide mobility. The key question is:

- Does the use of a pesticide in a given agricultural situation constitute a significant environmental risk with regard to ground-water contamination?

Fortunately, computer models which simulate the movement of pesticide in soils have been developed and can be applied with less expense and in far less time than field programs. Even so, with the extremely large number of chemical products and multiple soils, watershed and management combinations, the application of models in every case may not be justifiable.

In many cases, detailed analyses can be eliminated through the use of prior knowledge of the system involved. In other words, the pesticide/soil/crop/management variable combination could be screened to determine if leaching to ground-water occurs, and, if it does, to determine its frequency and severity. Such information would be extremely important in eliminating unnecessary use of resources for laboratory, field and modeling studies. To be useful, the procedure must be quickly and easily performed.

1.1 METHODOLOGY

This handbook presents the Leaching Evaluation of Agricultural Chemicals (LEACH) methodology by which new agricultural chemicals or chemicals being considered for alternative uses can be readily screened to determine whether they will move in significant quantities past the crop root zone. If significant leaching is predicted, the methodology provides a measure of its frequency and severity and/or indicates the necessity for more detailed analyses. LEACH integrates the effects of climate, soil properties, pesticide properties and management practices on pesticide leaching. It is quickly and easily used and requires minimal background and training on the part of its users.

1.2 SCOPE

This project was designed to identify pesticide/soil/crop/management combinations conducive to pesticide leachate production and quantify their effects on a national scale. At this level it is entirely possible, even probable, that certain critical areas which may be identifiable on a more localized scale have not been considered.

Because of the diversity of pesticide, soils, crop, climatic and managerial scenarios possible, some combinations were eliminated at the outset of the project in order to develop a feasible project scope. To delineate the scope with greatest facility, the following sections discuss the project scope limitations in each of our categories: pesticides, soils, management variables and crops.

1.2.1 Pesticide Properties

The methodology is limited to those pesticides which are hydrophobically adsorbed to soil materials according to linear and coincident adsorption/desorption isotherms. Pesticides which undergo significant (>95%) deprotonation (ionization) at normal soil pH levels should not be screened. This percentage can be easily determined (Mills, et al., 1982). The methods are designed only for a single pesticide in a soil/

water (two) phase system. They are not appropriate to pesticides dissolved in more than one solvent (e.g., water and toluene). Also, interactive effects (if such effects exist) of more than one pesticide are not considered. Neither are the methods generally applicable to pesticides which degrade to toxic daughter products with different decay and sorption characteristics from the parent.

1.2.2 Soil Properties

The soils are assumed to be relatively homogeneous in the horizontal and vertical directions. Soils should not have clay or plow pans, or any low permeability layers in the profile which would cause perched saturated conditions and/or lateral flow. Soils should be well dispersed, well drained and not subject to fracturing, cracking, swelling or shrinking.

1.2.3 Management Practices

The effect of management practices can only be evaluated to the extent that appropriate model parameter adjustments that describe their impacts can be estimated. In this methodology, the SCS runoff curve number technique is used to link management practices to infiltration, which is the driving force for pesticide leaching. Therefore, management scenarios capable of being treated are those which can be evaluated by this technique. These are, in general, limited to agricultural land use, tillage techniques and residue management.

Effects of non-structural management practices such as pesticide formulation, application mode and timing, or foliar versus soil application are not directly considered (See Section 3.5, Application Assumptions and Limitations).

1.2.4 Crops

The crops specifically considered in this handbook are corn, soybeans, wheat, and cotton. Thus, the geographic areas covered are where these crops are grown in significant quantities (See Section 4.4). Use of this methodology for other crops outside these geographical areas is not recommended. Because the effects of irrigation were not considered in developing the methodology, it does not take into account this agricultural practice. Irrigation may or may not result in greater quantities being transported through the soil profile. Artificially drained land may be considered as long as drains are placed below the crop rooting depth and rooting depths correspond to those used in model simulations (See Section 3.5.1).

Considering the above caveats it should be apparent that there has been considerable idealization of the real systems involved in order to provide a tractable scope. The serious user should be aware of the above and, in addition, carefully consider the assumptions and limitations at the end of Chapter 3. Even then, the results should be interpreted with caution and results indicating marginal or ambiguous environmental risks should be subjected to further analysis.

1.3 REQUIRED USER BACKGROUND, TRAINING AND PREPARATION

The mechanics of using this handbook are quite simple; that is, it is easy to generate the parameters necessary to locate the cumulative frequency distributions for a given scenario. The only practical requirement is that the user be acquainted with the Soil Conservation Service Runoff Curve Number technique. Even here the user is only asked to provide a curve number, not to carry the calculations through to a determination of runoff depth. The estimation of only one parameter requires the use of a hand calculator; the retardation factor, 'R'. A general knowledge of hydrology, soil physics and theory of contaminant migration in porous media is helpful.

Although the mechanical use of the handbook is straight-forward, effective application of the methodology requires good judgment and common sense by the user. The information inputs to obtain actual values for methodology parameters (e.g., pesticide decay rates, partition coefficients) are reported under a wide variety of non-standard conditions. Exact values are therefore subject to interpretation. Likewise, methodology outputs are subject to the assumptions and limitations of both its development and application. The user is urged to read and study these caveats and keep them in mind when making decisions which utilize methodology results. Reading of the entire handbook is recommended as a preparation for methodology use and especially the example applications in Section 5. Most information needed to perform analyses with this methodology are contained in this handbook. An exception is SCS soil infiltration information. In order to use the curve number technique, the Hydrologic Group must be known for the soils under consideration. Most soils in the U.S. are classified by the Soil Conservation Service by their potential to produce runoff. These classes (A, B, C, or D) are listed by the soil name in the SCS National Engineering Handbook (U.S.D.A., 1971), in County Soil Surveys, or in Carsel et al., (1984).

1.4 FORMAT OF THE MANUAL

This handbook, is divided into five sections, inclusive of this introduction. Section two (2) contains an overview of the methodology for determining the potential for pesticide leaching. Section three (3) contains a step-by-step discussion of the application procedure and parameter estimation techniques used to complete an assessment. This section concludes with specific inherent assumptions and limitations of the methodology. Section four (4) describes the development of this methodology and the specific steps and assumptions taken to generate the frequency distributions. Section five (5) contains two example applications. This is followed by references and two appendices as noted in the Table of Contents. The most important, Appendix A, contains address matrices and cumulative frequency distributions for determination of pesticide leaching probabilities.

SECTION 2

OVERVIEW OF THE METHODOLOGY

The purpose of this methodology is to provide the user with a means of evaluating the probability of "significant leaching" of a pesticide applied in an agricultural situation. The purpose of this section is to give a brief overview of how this is accomplished. First, however, it is of great importance to provide a definition of "significant leaching" as used here.

In this methodology, "significant leaching" is considered to be any movement (>0.05% of the annually applied chemical mass) of non-degraded pesticide (i.e., parent compound) past the rooting depth of the crop. This definition is both necessary and convenient in terms of methodology development because it allows the methods to ignore the complicating effects of local ground-water conditions on the fate of the pesticide. In order to perform a screening assessment of this type on a national scale, such local effects could not be feasibly considered. The rooting depth is a convenient datum because many pesticide attenuation processes, such as plant uptake, cease below this point and others, such as microbial degradation and soil adsorption may be less prominent. Therefore, below this depth, the pesticide can be considered, in a truer sense, more "conservative" than at some merely arbitrary datum in the soil profile. The adoption of this definition is inconvenient, however, to the user. The results alone cannot and should not be interpreted as an assessment of exposure to biological species or as data to compare to water quality criteria because the fate and transport processes in ground and/or adjacent surface waters have not been considered.

2.1 METHODOLOGY DEVELOPMENT

The approach was to use a pesticide leaching model that could integrate pesticide, climate, crop and soil characteristics, and management practices in order to generate time series of pesticide leached below the crop root zone. Several candidate models were investigated and PRZM (the Pesticide Root Zone Model), developed by the U.S. EPA, Athens Environmental Research Laboratory, was chosen. Sensitivity analyses were performed using the model to evaluate and quantify the impact of parameters most important to the leaching process. Then, using climatic, crop, soils, and pesticide usage information, nineteen (19) sites across the U.S. were delineated which are relatively homogeneous with respect to these characteristics. Twenty-five years of meteorologic data were then used to generate pesticide leaching sequences at important levels of the key parameters as determined by model sensitivity analyses. This resulted in over 47,000 model simulation years. In order to display this information in a usable fashion, the annual leaching time series were organized into cumulative frequency distributions. With 1900 potential curves, a matrix indexing system was derived to facilitate their organization and access. These matrices not only serve as tools to locate the frequency curves but also as screening tools for determining cutoff values of the key parameters, below which no significant leaching exists. An in-depth discussion of the methodology development and important assumptions can be found in Section 4.

2.2 ASSESSMENT OF SIGNIFICANT LEACHING

The procedure for assessing significant pesticide leaching is shown schematically in Figure 2.1. The first step is to select a crop and site targeted for use of the pesticide (Section 3.3). There are nineteen crop/site combinations possible. Once this has been done, data can be gathered to evaluate the three key parameters, essential to the methodology (Section 3.4); the pesticide decay rate, the retardation factor for the pesticide/soil combination and the runoff curve number for the soil/crop management scenario. Each site number (1 through 19) corresponds to a matrix in Appendix A (A1 through A19). These matrices are used to determine if significant leaching occurs and to locate the cumulative frequency curves which indicate severity as follows.

The pesticide decay rate and retardation factor are used to enter the matrix. The matrix entries are figure numbers which correspond to figures located in Appendix A. If there is no figure number corresponding to the nearest values of retardation factor and decay rate, then there is no significant leaching associated with the use of the pesticide in this circumstance. Quantitatively, this means that there was no year during the simulation period in which greater than 0.05 percent of the annually applied pesticide leached below the crop rooting depth.

If the retardation factor and decay rate fall within the portion of the matrix containing figure number entries, then the user may proceed to find the corresponding figure or figures. Each of these figures contains a family of cumulative frequency distributions. Each member of this family is associated with a runoff curve number. The user selects the curve having a runoff curve number closest to the estimated value for the site/scenario conditions. Thus, the user has located a frequency distribution which corresponds to a region of the United States with a crop/soil/pesticide/management scenario described by the computed values of pesticide decay rate, retardation factor and runoff curve number. These figures have on the x-axis the percentage of annually applied pesticide leached past the crop rooting depth, and on the y-axis, the percentage of time that the value on the x-axis will be exceeded. (See Sections 2.3 and 3.4).

These cumulative frequency distributions, which will be referred to as CDFs (cumulative density functions), can be used in subsequent analyses, as discussed in Section 2.3.

2.2.1 Sensitivity Analysis

It is likely that there will be enough uncertainty in the input information that single values of the key parameters derived from this information may seem inadequate. For instance, it is possible that the adsorption partition coefficient for the compound has reported or computed values which range from 1 to 6 giving values of the retardation factor from approximately 7 to 37, although the most likely value of retardation might be 10. It is informative to know how the methodology results change as the retardation factor goes from 7 to 10 to 37. If the frequency curves change greatly over these retardation values or the result changes from a significant leaching to a no leaching situation, or vice versa, then the user would naturally have less confidence in the result (arising from the uncertainty in this parameter) than if changing the retardation factor produces little effect. Such sensitivity analysis can be performed using any or all of the three key parameters. In general the user will find that sensitivity to runoff curve number will decrease as decay rate increases and retardation increases. Sensitivity to decay rate will increase as retardation decreases and curve number decreases. Sensitivity to retardation factor will increase as decay rate and curve number decrease. Example application number two (Section 5) contains an example of such a sensitivity analysis.

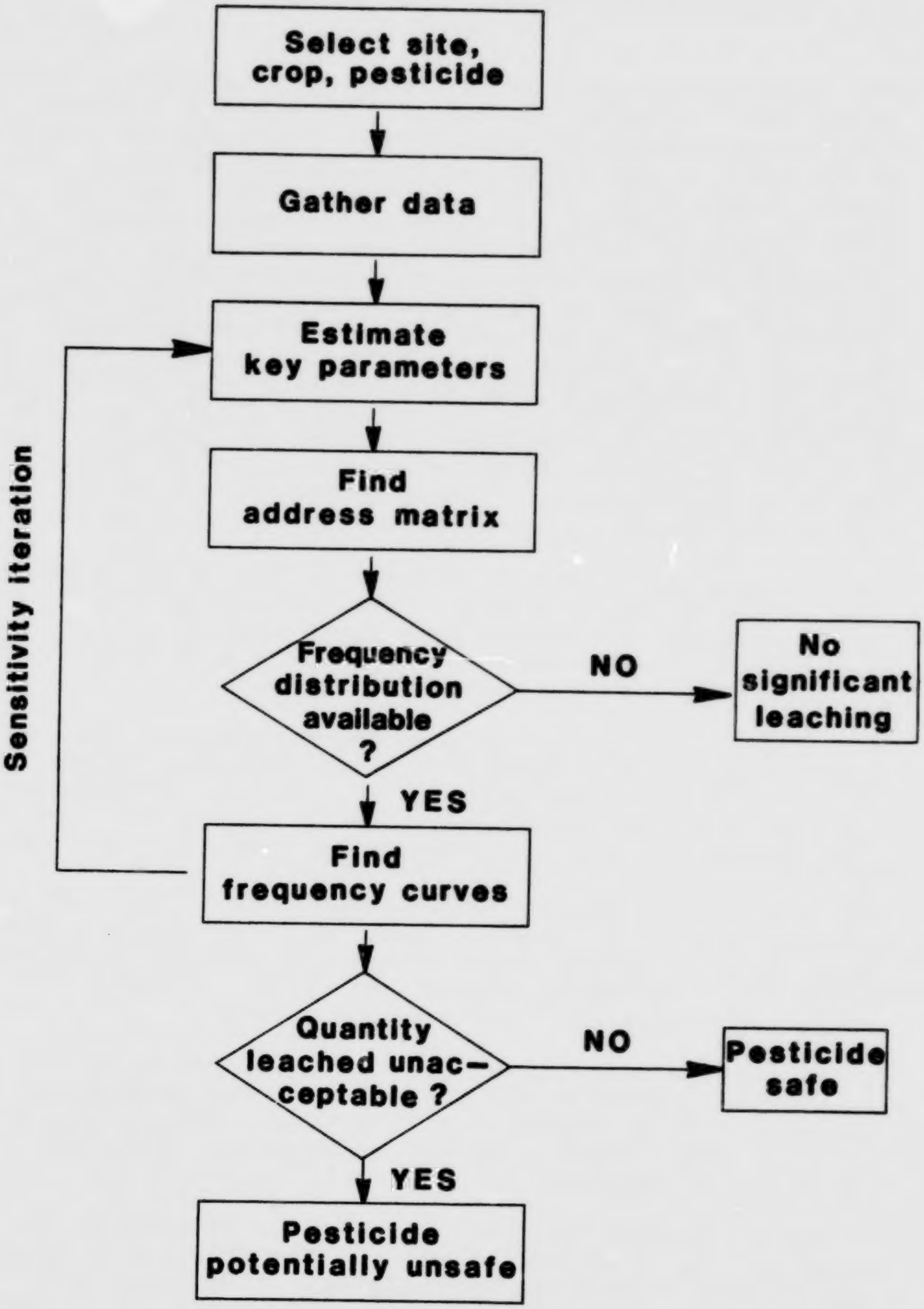

Select site, crop, pesticide
Gather data
Estimate key parameters
Find address matrix
Frequency distribution available ?
NO
No significant leaching
YES
Find frequency curves
Sensitivity iteration
Quantity leached unacceptable ?
NO
Pesticide safe
YES
Pesticide potentially unsafe

Figure 2.1 Schematic for Pesticide Leaching Evaluation

2.3 INTERPRETATION AND USE OF RESULTS

The methodology gives the user very specific information about the leaching of a pesticide under a certain climate /soil/crop/management situation. First, if the retardation/ decay rate combination for a given site falls in the blank lower right hand corner of the address matrix, then no significant leaching (<0.05% of annually applied quantity) was observed in the 25 year simulation period. If sensitivity iterations give combinations which all fall into this region, then it is a good assumption that no significant leaching would occur from the use of the compound. It must be remembered, however that pesticide toxicity plays a major role in determining if the presence of a given level of pesticide in water or soil is safe or unsafe. The 0.05% level was somewhat arbitarily chosen but probably represents a level that is safe given the toxicity of most currently available pesticides. Levels of this magnitude in pesticide runoff studies are generally considered to be safe.

For borderline cases in which sensitivity analyses indicate some significant leaching situations or for cases in which large amounts of pesticide would appear to be leaching, subsequent "post screening" analyses are warranted. The CDFs in Appendix A will be useful in such cases.

The CDFs give an estimate of the probability that a certain annual pesticide loading rate will result below the crop rooting depth. The next logical step in determining if the use of the pesticide constitutes a substantial risk to the environment is to develop concentrations in ground water.

To arrive at these concentrations the mass of pesticide leached must be mixed in some volume of water. This can be done fairly simply but there are several cautions worth mentioning in this regard which are brought out in the following discussion, and are underscored.

A simplified scenario of pesticide loading to ground water is shown in Figure 2.2. The source area discharges leachate directly to the aquifer in this case. Notice that the bottom of the root zone does not necessarily coincide with the ground-water table.

A concentration for our purposes is defined as a mass of chemical in a volume of water. The CDFs which result from application of this methodology give the mass loadings exiting the root zone a certain percentage of the time for a unit portion of the source area. Unless the ground-water table is very close to the bottom of the root zone, the quantity of leachate reaching ground water may be different

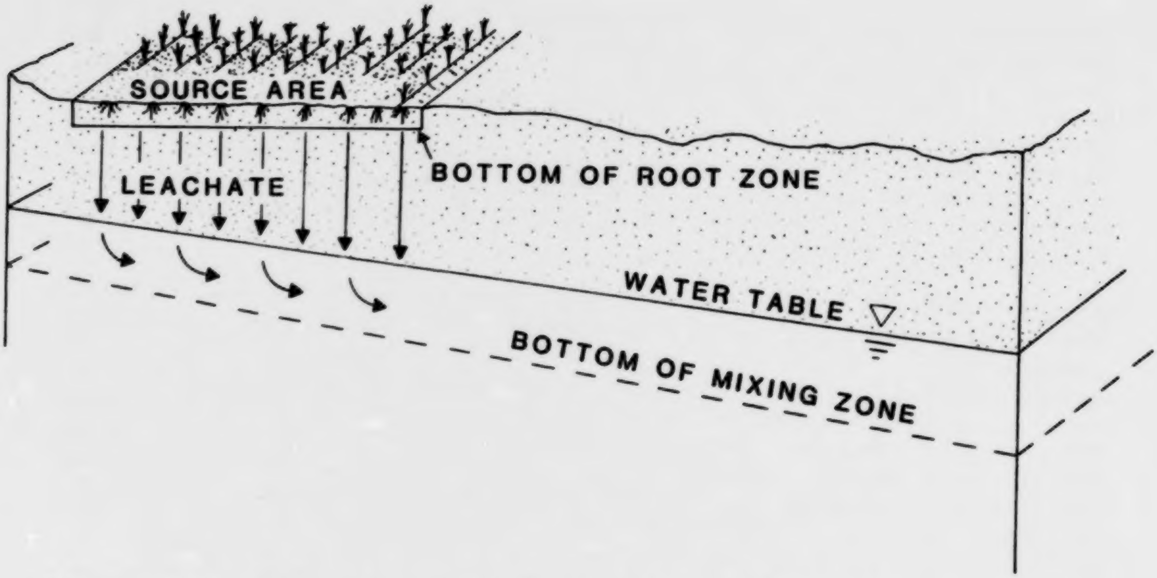


Figure 2.2 Schematic of agricultural chemical contamination of groundwater under a scenario of direct recharge.

from that exiting the root zone due to decay. Of course a "worst case" scenario would assume that no decay occurs; hence, the bottom of the root zone loadings would equal ground-water loadings under "steady-state" conditions. The chemical will then be mixed in ground water to a certain depth (the mixing depth). By knowing the area of the source (assuming that this area and the contact area of ground water by leachate are equivalent) and the mixing depth, a volume of contaminated ground water can be determined immediately beneath the source and a concentration can be obtained. An inherent assumption in this approach is that the recharge volume from the source area is negligible compared to the mixing volume. This contaminated water will be advected in the direction of ground-water flow. Normally, the mixing depth becomes greater in this direction because of diffusion and dispersion of the chemical. The plume also will spread horizontally. Due to this dispersion, decay of chemical and possible additional recharge the concentrations will decrease as the chemical moves downgradient in the aquifer. Thus concentrations depend crucially at where and when one looks in the aquifer.

Further complications arise when confining layers occur between the root zone and the ground-water aquifer.

This type of analysis can only be done by knowing specific localized information, such as depth to ground water and transport and fate characteristics in the aquifer. Concentrations can be calculated at the screening level by using simplified techniques e.g., Donigian, et al., (1983); Brown (1983), or at a higher level by using numerical ground-water simulation models of which there are many. In either case, the CDF is used as a "loading function," and the ground-water model as a transfer function to generate frequency distributions of concentrations at various times and points in the aquifer.

Notice also that in the preceeding discussion it was stated that the CDFs give an estimate of pesticide leaching probability. Only a single 25 year historical sample of meteorological data was used to generate these estimates. To get a better estimate, many 25 year sequences might be run. This would result in a "distribution about the CDFs" from which confidence limits could be estimated. This has not been done because of the obvious time and expense required. Another way of "improving" this estimate would be to fit probability density functions (e.g., log normal or gamma) to each sample density function This would result in "tails" to the right on each CDF instead of the oblique angles at which some curves intersect the x-axis on the plots (See Appendix A). Because no one PDF could be found to fit all the samples and because of the small sample size (25 points) this was not done. Tail probabilites based on such a small sample might be grossly misleading. Therefore the samples were simply fit with 4th-order polynomials and the resulting curves appear in Appendix A. The percent of time that annual pesticide leaching exceeds a given level should not be strictly interpreted as a probability.

2.4 CONCLUSIONS

The production and subsequent use of a methodology to establish the leaching potential of pesticides applied under different soil/crop/management scenarios has brought out some important issues concerning the understanding of contaminant migration in soils.

- First, through the use of model sensitivity analysis it has been shown that three parameters have major impact upon contaminant movement. These are the pesticide decay rate, the pesticide/soil retardation factor and the infiltrated quantity of water through the profile. Because the retardation factor and decay rate can vary so widely (over several orders of magnitude) they are the most important parameters.

In general, it is shown that at values of retardation factor greater than 50 no indications of leaching of the compound past the crop rooting depth were found (<0.05% of applied quantity) during the 25 year simulation period, irrespective of quantity of infiltrated water or pesticide decay rate. This simple fact eliminates the necessity of applying the methodology for most pesticides with such large retardation factors. At values of retardation less than 50, the movement of contaminants becomes more sensitive to other factors. As decay rate goes to zero (conservative substance) and the retardation factor goes to 1 (completely mobile, non-adsorbing chemical) the amount of water infiltrated plays the greatest role in determining the leached quantity.

It should be noted that soil and water conservation management practices (as evidenced by curve number) have only a minor impact on this quantity. Climatic regime (i.e., precipitation quantity, intensity and evaporation rates) have a much more pronounced effect. This is evidenced by the fact that changing sites can have a greater impact on the percentage leached than changing curve numbers (at equal values of decay and retardation). While a curve number has maximum effect on pesticides with low affinity for soils, i.e., low organic carbon partition coefficient, Koc, (as defined in Section 3.3) the effects of factors such as soil bulk density, organic carbon, and porosity are only pronounced at intermediate values of Koc. That is, if Koc is extremely low the effect of the soil characteristics on leaching is almost negligible.

Of course if the decay rate is very high, the importance of adsorption in general is lessened. Thus for short-lived, mobile chemicals, the key management factor is the timing between pesticide application and the next major rainfall event.

As half-life becomes longer and adsorption coefficients higher, soil factors begin to play a major role. Thus management practices that reduce infiltration, increase organic carbon or increase bulk density would be effective in reducing leaching. Of course these factors are not independent. For instance, increasing organic carbon will likely increase infiltration rates and decrease bulk density. At higher adsorption and higher decay rates, as mentioned earlier, leaching becomes an unimportant issue.

- The second major conclusion is that the parameter inputs to the methodology are in general so inexact that the use of quoted ranges give vastly different results (See Section 5, Example Applications). This indicates a need to develop more consistent and meaningful techniques for measuring parameters such as decay rates, Koc, etc. There are two primary sources of error involved in modeling; error caused by inexact model inputs and error caused by inexact model descriptions of actual processes by model algorithms. Reducing either or both of these results in diminished overall simulation error. Thus, if the variability in input parameters is reduced, the use of this handbook and modeling in general as predictive tools is enhanced.

SECTION 3

APPLICATION PROCEDURE FOR ASSESSMENT OF LEACHING POTENTIAL

3.1 INTRODUCTION

This section provides a step-by-step guide for the application of the methods contained in this handbook. The user's inputs (site selection and parameter estimation) are discussed as well as interpretation of the frequency distributions used to make decisions about potential pesticide leaching. Finally, the assumptions and limitations of the application are discussed.

As described in earlier sections, the user inputs required are few, but must be determined from a variety of sources. Much of the information can be found in tables located in the appendices of this report or in referenced documents. To apply the methodology the user must locate and choose representative values for:

- site characteristics
  - hydrologic soil group
  - soil organic carbon and bulk density
- crop type
- pesticide properties
  - organic carbon partition coefficient, Koc (or Kow)
  - decay rate, Ks, and
- management practices
  - used to determine the SCS curve number

A chart showing this flow of information appears in Figure 3.1. The following sections explore site selection and parameter estimation in detail.

Once a set of input values has been developed, they can be used to find the cumulative frequency distributions, located in Appendix A. The method for choosing appropriate curves and their interpretation is provided in Sections 3.3 through 3.5.

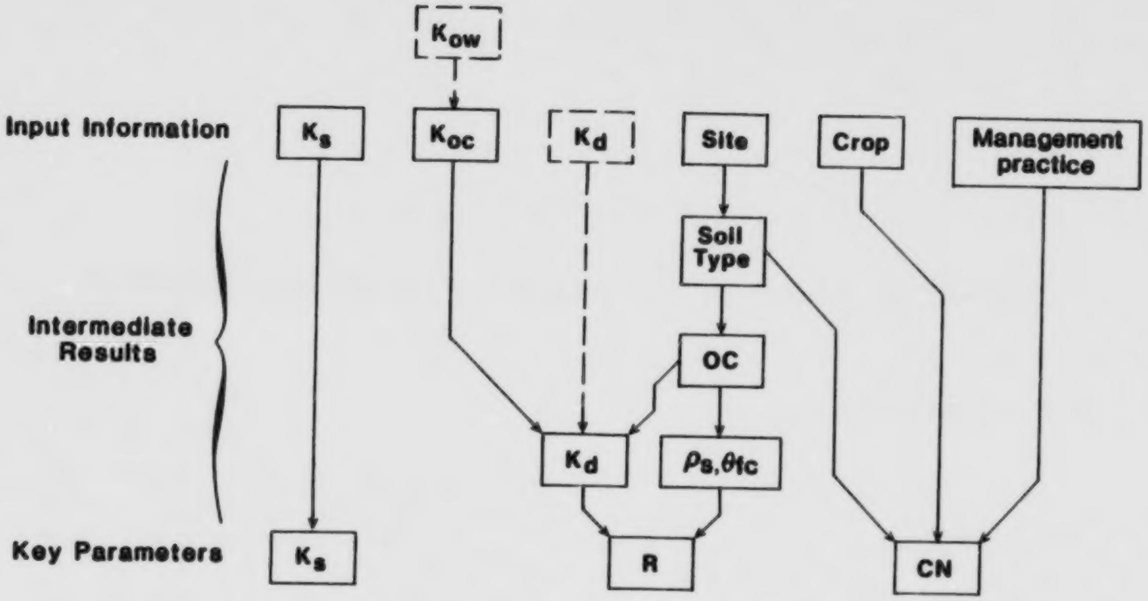


Figure 3.1 Schematic of Information Flow to Calculate Methodology Key Parameters

3.2 SITE SELECTION

The site selection process is required as part of the application procedure to find a representative site, delineated in this handbook, that corresponds to the area or region where an assessment is needed. The selection procedure requires only knowledge of geographical location and crop type of concern. Nineteen representative sites were delineated by combining meteorologic, soils, crop distribution, and pesticide usage data. Each site is characterized by a unique set of descriptors displayed in Table 3.1. Development of the criteria used in site delineation can be found in the Methodology Development section of this report (Section 4.4). Maps of the 19 representative sites are displayed by crop in Figures 3.2 through 3.5.

The first step in choosing a representative site is to locate the user's site or region of interest on the maps provided. The four maps are distinguished by their associated crops; wheat, corn, soybeans, and cotton. Some sites overlap each other (especially in the corn and soybean regions). It is necessary to use the map that corresponds to the crop of interest. Although representative sites cover the major crop

TABLE 3.1 METEOROLOGIC AND SOILS CHARACTERISTICS OF REPRESENTATIVE SITES

Site No.	Meteorologic Station Location		Annual Precip(in)	Soil Group	Crop	% Organic Carbon
	State	Station No.				
1	WA	8926	20-30	C	Wheat	0.5-2.0
2	ID	10	10-20	B-C	Wheat	0.5-1.0
3	MT	3110	20	A-C	Wheat	1.0-2.0
4	ND	5479	20	B-C	Wheat	1.0-2.0(+)
5	NE	4455	10-20	A-C	Wheat	1.0-2.0
6	KS	1383	20-30	A	Wheat	1.0-2.0
7	CO	834	10-20	C	Corn	1.0-2.0
8	NE	3395	20-30	D	Corn	1.0-2.0(+)
9	IL	8179	40	C	Corn	1.0-2.0(+)
10	MI	7690	30-40	B	Corn	1.0-2.0(+)
11	OH	1466	40	B	Corn	1.0-2.0
12	MD	700	40	C	Corn	1.0-2.0
13	SC	1726	50-60	C-D	Corn	0.0(+)-1.0
14	IA	205	30-40	B	Soy	1.0-2.0(+)
15	MS	1707	50	B-C	Soy	0.0(+)-1.0
16	IN	6506	40	B	Soy	1.0-2.0
17	SC	1726	50-60	C-D	Soy	0.0(+)-1.0
18	LS	1411	50-60	C-D	Cotton	0.0(+)-1.0
19	AL	5140	50	B-C	Cotton	0.5-1.0

(1" = 2.54 cm)

growing areas, these crops are often grown outside the regions shown. If the area of interest does lie outside of the representative site boundaries, the user should be aware of the precipitation and soils characteristics in the area of interest and choose a site with the same crop and similar characteristics. (See Section 4.4 and Example #2, Section 5). The characteristics that should conform are average annual precipitation, hydrologic soil group, soil texture (sand/silt/clay), soil organic carbon, and suitability of the soil for growing the crop of interest.

An example of the site location procedure follows:

- Example crop of interest - soybeans
- Example site of interest - southern tip of Illinois

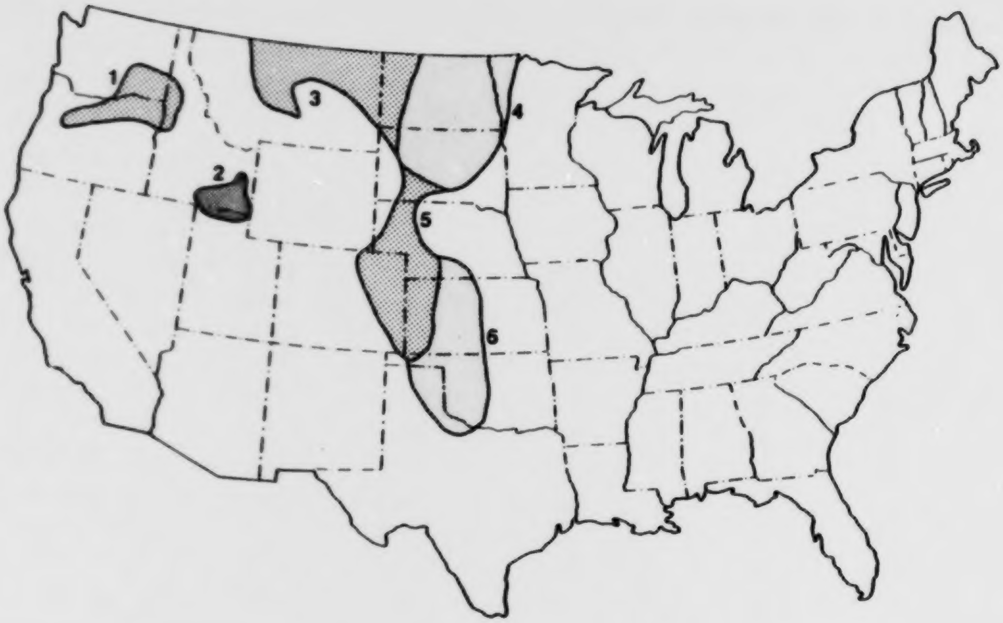
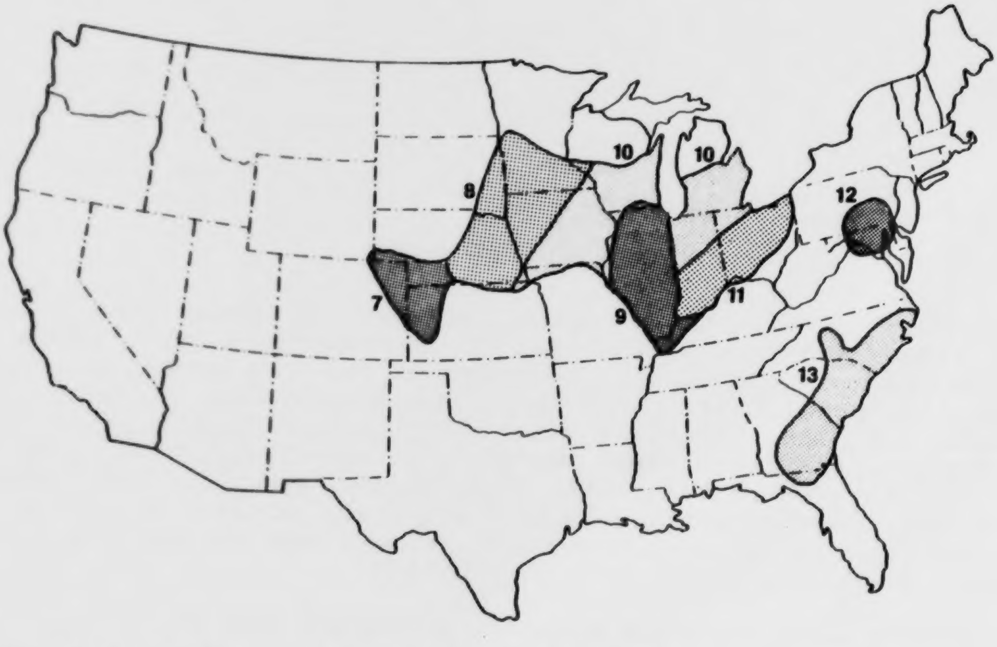


Figure 3.2 Representative Sites No. 1 - No. 6 Associated with Wheat Farms


7
8
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10
10
11
12
13

Figure 3.3 Representative Sites No. 7 - No. 13 Associated with Corn Farms

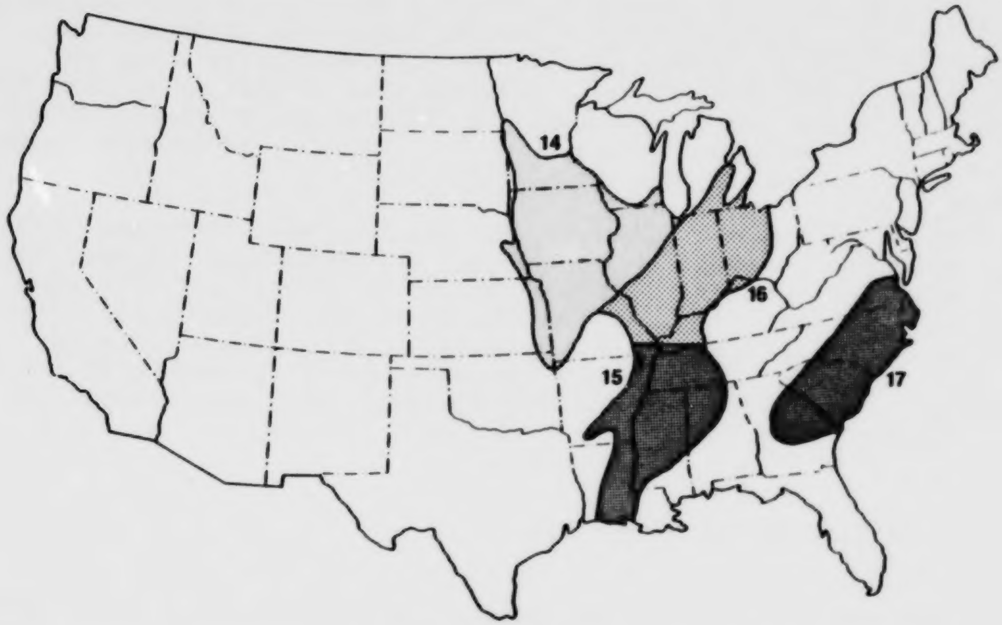


Figure 3.4 Representative Sites No. 14 - No. 17 Associated with Soybean Farms

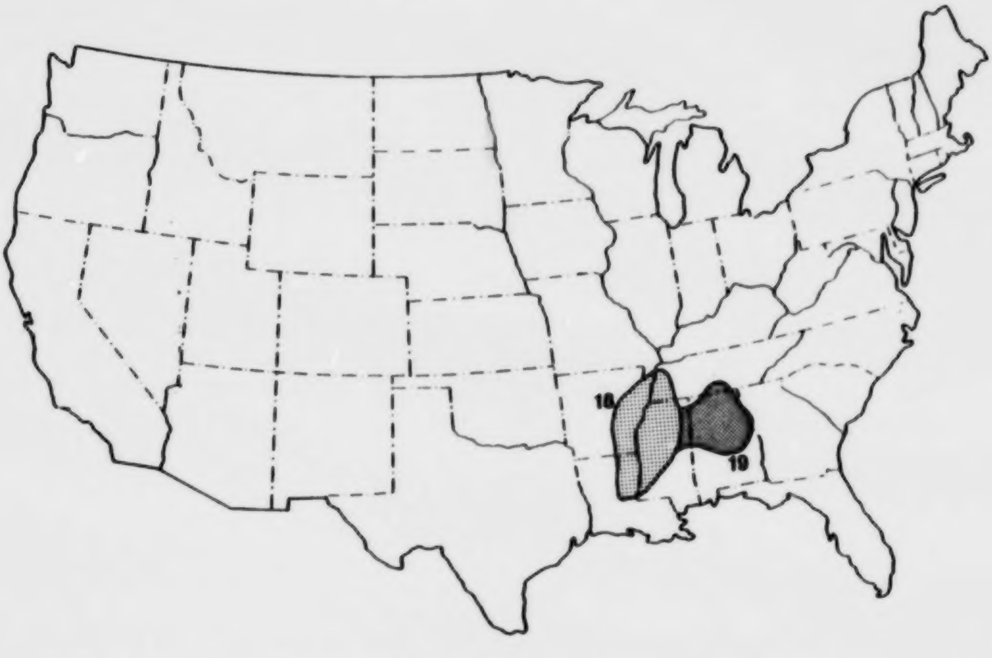


Figure 3.5 Representative Sites No. 18 - No. 19 Associated with Cotton Farms

- Turn to Figure 3.4 (sites associated with soybeans)
- Locate site of interest (southern Illinois) on map - site lies within representative site #16

Note: The meteorologic station that provided weather data for development of the cumulative frequency distributions (Appendix A) for site #16 is station number 6506 in Indiana (Table 3.1).

If the example site of interest had been southern Missouri, the user would choose between representative sites 14, 15, and 16. This would require investigation into the meteorologic regime, and the soils characteristics (outlined earlier) for southern Missouri. These characteristics would be compared to those of representative sites 14, 15, and 16. Basic information used to delineate each representative site is listed in Table 4.1 of the next section.

3.3 PARAMETER ESTIMATION

The use of this handbook requires calculation of three parameters; the retardation factor (R) for the pesticide/soil combination, the pesticide decay rate (Ks), and a soil/crop management curve number (CN) determined by the SCS method. These parameters are shown at the bottom of Figure 3.1. All of the information required for the computations are outlined below with supplementary material to be found in Appendix B (chemical data for some currently used pesticides). Note that the pesticide of interest may not be found in Appendix B. In this case the user will need to locate an appropriate data source. Additional pertinent soils data can be found in SCS county soil surveys.

3.3.1 Retardation Factor, R

The retardation factor requires determination of the chemical partition coefficient (Kd), the soil bulk density (ρs), and the average soil water content at field capacity (θfc). The equation is

$$R = 1 + \frac{(Kd)\ (\rho s)}{\theta fc} \qquad 3.1$$

where R is dimensionless, Kd has units of cc/g-soil, ρs has units of g-soil/cc and θfc has units of cc/cc.

$$Kd = Koc\,(OC)/100 \tag{3.2}$$

where Koc is the organic carbon partition coefficient having units of cc/g-organic carbon and OC is the percent soil organic carbon. If Kow (octanol-water partition coefficient) or S (solubility) is reported instead of Koc, several empirical functions can be used to convert to Koc. These can be found in Table 3.2. Compilations of Kow, Koc and Kd for some pesticides can be found in Tables B1 through B4. An excellent source of solubility data for herbicides is available (Weed Science Society of America, 1983) if the compound's Kow or Koc cannot be found in the literature.

No compilations of soil organic carbon on a national scale have been found in the literature. In the absence of this specific data, soil nitrogen content can be used as a surrogate. The organic carbon to nitrogen ratio in the soil is approximately 11 to 1 (Brady, 1974). Thus OC = 11N, where N is % nitrogen or g-N/100g-soil. Nitrogen content of surface soils in the United States can be estimated from the map,(Figure 3.6).

Once the soil type is known, the textural classification (Figure 3.7) provides sufficient information to estimate bulk density (ρs) (Table 3.3) and the field capacity water content (θfc), which can be determined from the regression equation in Figure 3.8 or from Table 3.4. If the user has access to profile information for the soil of interest, it may be desireable to either use weighted mean values of OC, ρs and θfc for the profile, or introduce this variability into sensitivity analysis of the retardation factor.

3.3.2 Decay Rate, Ks

Values of Ks for many agricultural chemicals are shown in Tables B5 and B6. Extreme care should be taken in using the decay rates reported in Appendix B. There are two important potential problems. First, these rates have been measured under a wide range of environmental conditions, (e.g., varying soils, soil pH, soil organic matter, soil moisture, soil temperature, etc.) which can have dramatic effects on reported values. The user should check the original references to ascertain what these conditions were and the applicability of these conditions to his or her specific situation. These references can be found in Nash (1980). Secondly, in this methodology, the decay rate is applied to both dissolved and adsorbed chemical. The user should be satisfied that this condition was met in the measurement of

TABLE 3.2 REGRESSION EQUATIONS FOR THE ESTIMATION OF K_{oc}

Eq. No.	Equation[a]	No.[b]	r^2[c]	Chemical Classes Represented
1	$\log K_{oc} = -0.55 \log S + 3.64$ (S in mg/L)	106	0.71	Wide variety, mostly presticides
2	$\log K_{oc} = -0.54 \log S + 0.44$ (S in mole fraction)	10	0.94	Mostly aromatic or polynuclear aromatics; two chlorinated
3[d]	$\log K_{oc} = -0.557 \log S + 4.277$ (S in moles/L)	15	0.99	Chlorinated hydrocarbons
4	$\log K_{oc} = 0.544 \log K_{ow} + 1.377$	45	0.74	Wide variety, mostly pesticides
5	$\log K_{oc} = 0.937 \log K_{ow} - 0.006$	19	0.95	Aromatics, polynuclear aromatics, triazines and dinitroaniline herbicides
6	$\log K_{oc} = 1.00 \log K_{ow} -0.21$	10	1.00	Mostly aromatic or polynuclear aromatics; two chlorinated
7	$\log K_{oc} = 0.94 \log K_{ow} + 0.02$	9	[e]	s-Triazines and dinitroaniline herbicides
8	$\log K_{oc} = 1.029 \log K_{ow} - 0.18$	13	0.91	Variety of insecticides, herbicides and fungicides
9[d]	$\log K_{oc} = 0.524 \log K_{ow} + 0.855$	30	0.84	Substituted phenyluraes and alkyl-N-phenylcarbamates
10d,f	$\log K_{oc} = 0.0067 (P - 45N) + 0.237$	29	0.69	Aromatic compounds: ureas, 1,3,5-triazines, carbamates, and uracils
11	$\log K_{oc} = 0.681 \log BCF(f) + 1.963$	13	0.76	Wide variety, mostly pesticides
12	$\log K_{oc} = 0.681 \log BCF(t) + 1.886$	22	0.83	Wide variety, mostly pesticides

a. K_{oc} = soil (or sediment) adsorption coefficient; S = water solubility, K_{ow} = octanol-water partition coefficient; BCF(f) = bioconcentration factor from flowing water tests, BCF(t) = bioconcentration factor from model ecosystems; P - parachor; N = number of sites in molecule which can participate in the formation of a hydrogen bond.

b. No. = number of chemicals used to obtain regression equation.

c. r^2 = correlation coefficient for regression equation.

d. Equation originally given in terms of K_{om}. The relationship $K_{om} = K_{oc}/1.724$ was used to rewrite the equation in terms of K_{oc}.

e. Not available.

f. Specific chemicals used to obtain regression equation not specified.

Source: Lyman, et al., 1982

the decay rate or find another source of information about degradation of the compound.

For compounds not listed in the tables, registration documents for the specific pesticide available through the U.S. EPA or the chemical manufacturer may contain appropriate values. For use in this methodology, the units for Ks must be per day.

3.3.3 Curve Number, CN

To incorporate both soil characteristics and land management practices into the system, the Soil Conservation Service curve number method is used. To estimate these numbers, soil infiltration characteristics, watershed hydrologic conditions, and conservation management practice should be known.

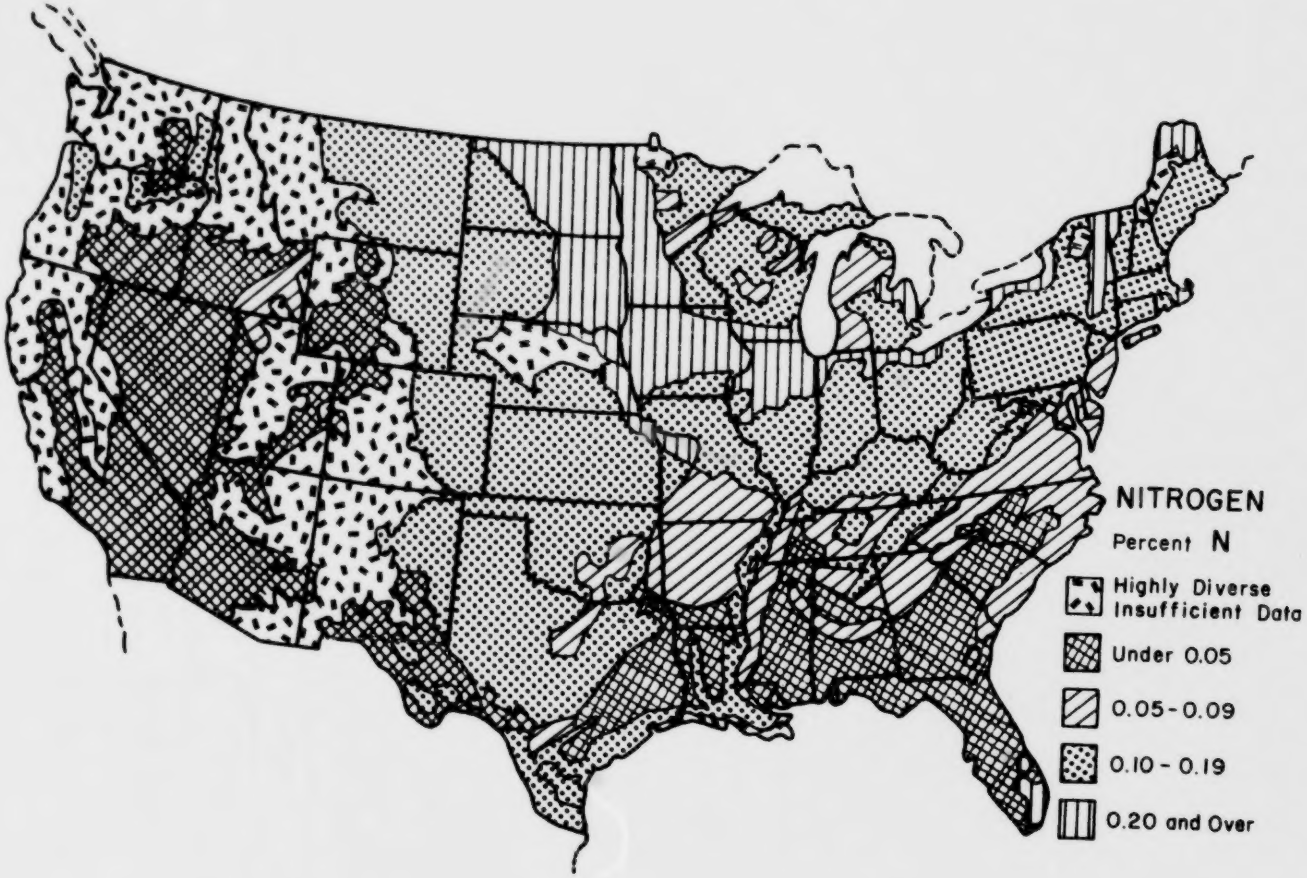
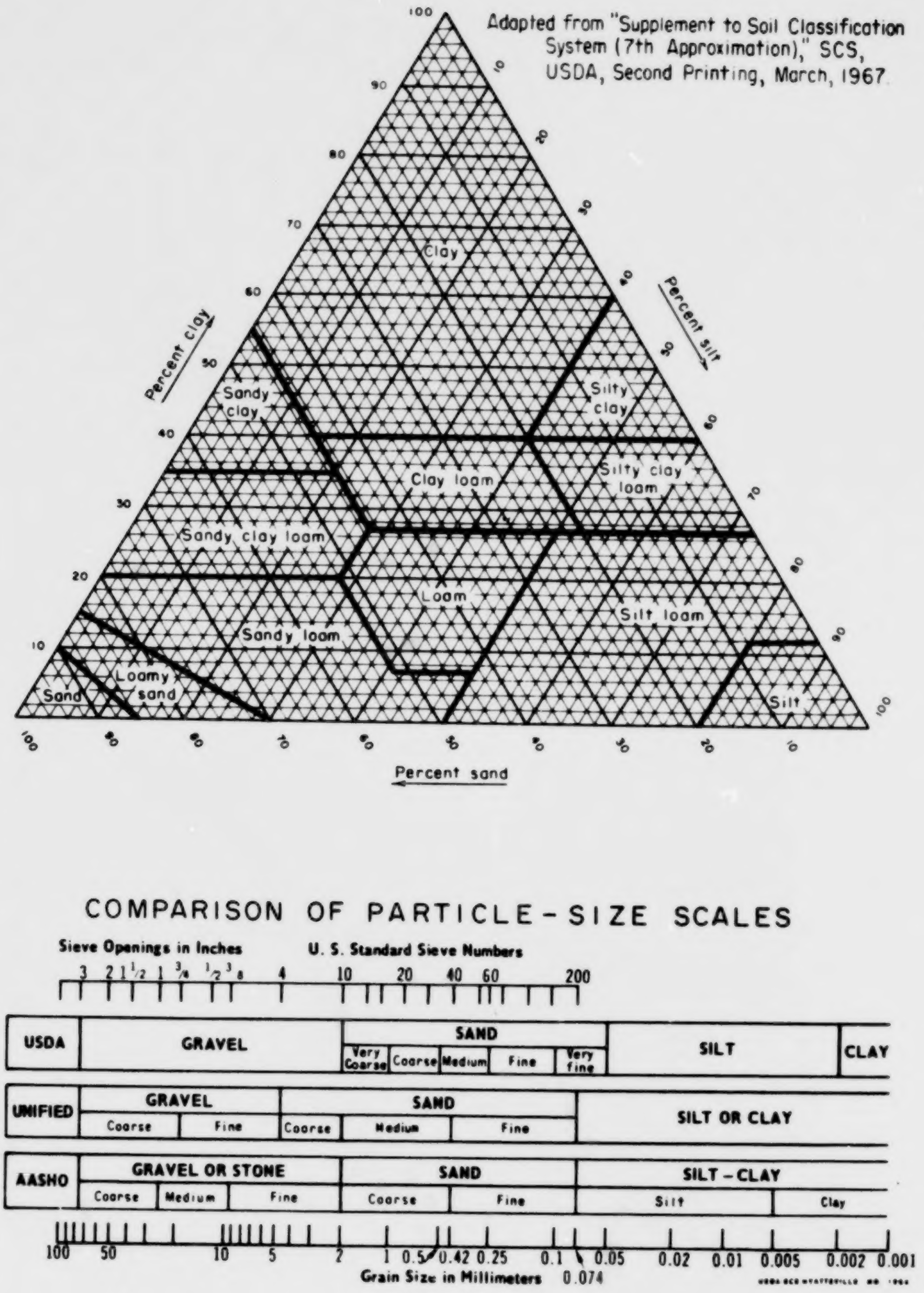

NITROGEN
Percent N
Highly Diverse Insufficient Data
Under 0.05
0.05-0.09
0.10 - 0.19
0.20 and Over

Figure 3.6 Percentage Nitrogen (N) in Surface Foot of Soil
Source: Parker, et al., 1946



Adapted from "Supplement to Soil Classification System (7th Approximation)," SCS, USDA, Second Printing, March, 1967

Percent clay
Percent silt
Percent sand
100
90
80
70
60
50
40
30
20
10
Clay
Silty clay
Sandy clay
Clay loam
Silty clay loam
Sandy clay loam
Loam
Silt loam
Sandy loam
Loamy sand
Sand
Silt
COMPARISON OF PARTICLE-SIZE SCALES
Sieve Openings in Inches
3 2 1½ 1 ¾ ½ ⅜
U. S. Standard Sieve Numbers
4 10 20 40 60 200
USDA
GRAVEL
SAND
Very Coarse
Coarse
Medium
Fine
Very fine
SILT
CLAY
UNIFIED
GRAVEL
Coarse
Fine
SAND
Coarse
Medium
Fine
SILT OR CLAY
AASHO
GRAVEL OR STONE
Coarse
Medium
Fine
SAND
Coarse
Fine
SILT – CLAY
Silt
Clay
100 50 10 5 2 1 0.5 0.42 0.25 0.1 0.05 0.02 0.01 0.005 0.002 0.001
0.074
Grain Size in Millimeters

Figure 3.7 Relationship Between the Class Name of a Soil and its Particle Size Distribution

TABLE 3.3 ESTIMATED SOIL BULK DENSITY FOR FIVE SOIL TYPES

Soil type	No. observed	Mean	Observed range
Silt loams	99	1.32	0.86 to 1.67
Clay & clay loams	49	1.30	0.94 to 1.54
Sandy loams	37	1.49	1.25 to 1.76
Gravelly silt loams	15	1.22	1.02 to 1.42
Loams	22	1.42	1.16 to 1.58
All soils	222	1.35	0.86 to 1.76

Source: Baes and Sharp, 1983

Each soil belongs to a hydrologic soil group, designated A, B, C, or D. These index letters define the soil's infiltration capacity. A description of hydrologic soil classifications is found in Table 3.5. Most soils of the U.S. have been classified by the U.S.D.A. (1971) using this system.

Cropping practices as well as soil type affect the soil's ability to transmit water. The hydrologic condition reflects the amount of dense vegetation in each rotation. Poor hydrologic conditions result from repeated rotations of the same crop in the same field. Good hydrologic conditions result from incorporation of legumes or grasses in rotations to improve the infiltration characteristics of the soil.

Land use management information also affects curve number selection. Variation in curve numbers reflects runoff potential associated with straight row, contoured, or contoured and terraced lands.

Knowing the above information a runoff curve number can be located in Table 3.6. The user's CN should lie within the

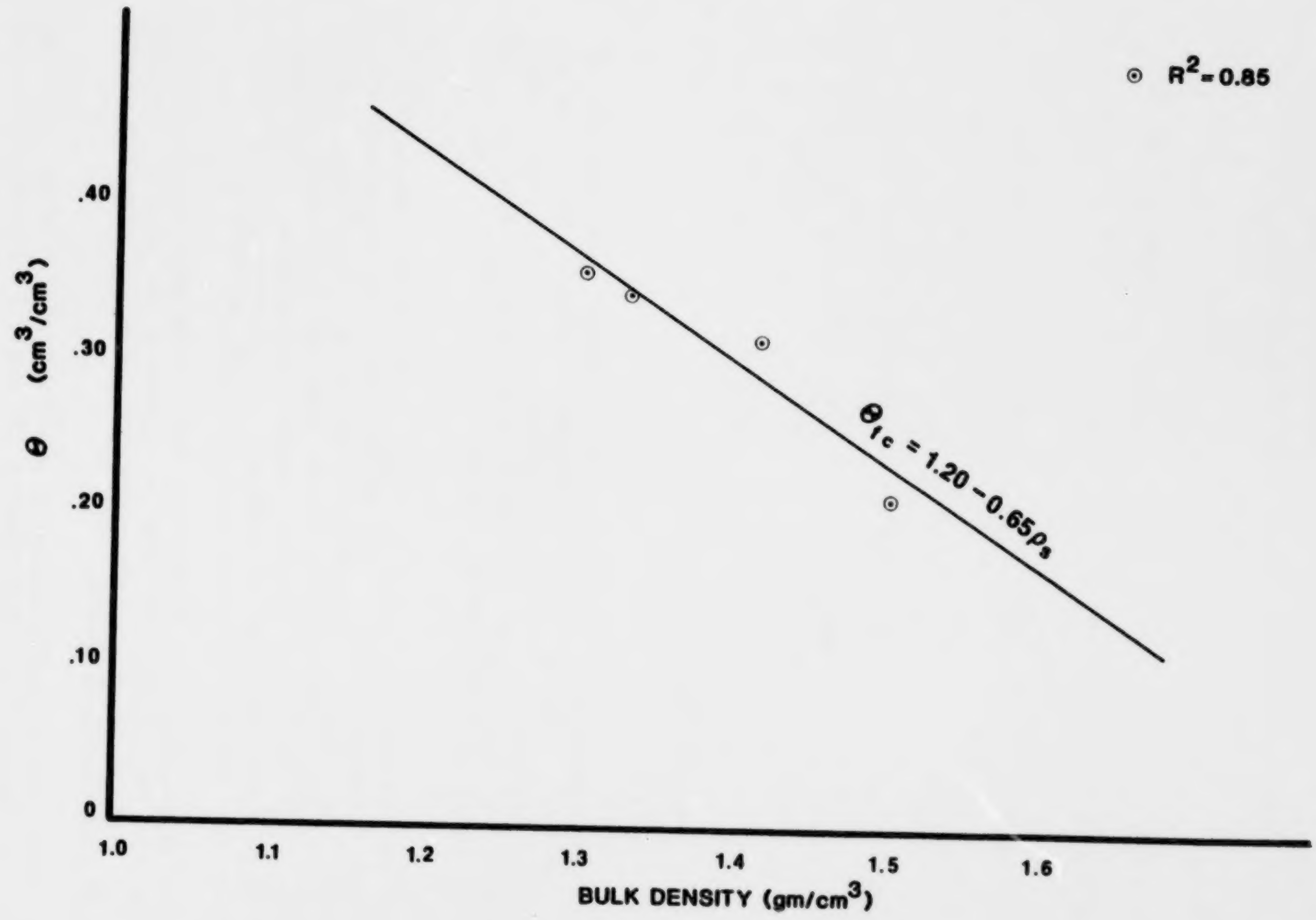


Figure 3.8 Analysis of Bulk Density and Field Capacity Relationships

TABLE 3.4 SOIL HYDROLOGIC PROPERTIES BY SOIL TEXTURE

Texture Class	Range of Textural Properties Percent			Water Retained at -0.33 bar tension cm^3/cm^3
	Sand	Silt	Clay	
SAND	85-100	0-15	0-10	0.091[1] (0.018 - 0.164)[2]
LOAMY SAND	70-90	0-30	0-15	0.125 (0.060 - 0.190)
SANDY LOAM	45-85	0-50	0-20	0.207 (0.126 - 0.288)
LOAM	25-50	28-50	8-28	0.270 (0.195 - 0.345)
SILT LOAM	0-50	50-100	0-28	0.330 (0.258 - 0.402)
SANDY CLAY LOAM	45-80	0-28	20-35	0.257 (0.186 - 0.324)
CLAY LOAM	20-45	15-55	28-50	0.318 (0.250 - 0.386)
SILTY CLAY LOAM	0-20	40-73	28-40	0.366 (0.304 - 0.428)
SANDY CLAY	45-65	0-20	35-55	0.339 (0.245 - 0.433)
SILTY CLAY	0-20	40-60	40-60	0.387 (0.332 - 0.442)
CLAY	0-45	0-40	40-100	0.396 (0.326 - 0.466)

[1] mean value

[2] one standard deviation about the mean

Source: Rawls, et al., 1982

TABLE 3.5 HYDROLOGIC SOIL CLASSIFICATIONS

Group/Runoff Potential	Description
Group A. Low Runoff Potential	Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well-to excessively-drained sands or gravels. These soils have a high rate of water transmission.
Group B. Moderately Low Runoff Potential	Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well-drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.
Group C. Moderately High Runoff Potential	Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.
Group D. High Runoff Potential	Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

Source: USDA (1971)

TABLE 3.6 RUNOFF CURVE NUMBERS FOR HYDROLOGIC SOIL-COVER COMPLEXES (ANTECEDENT MOISTURE CONDITION II, AND $I_a = 0.2$ S)

Cover			Hydrologic soil group			
Land use	Treatment or practice	Hydrologic condition	A	B	C	D
Fallow	Straight row	----	77	86	91	94
Row crops	Straight row	Poor	72	78	85	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Contoured and terraced	Poor	66	74	80	82
	Contoured and terraced	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Contoured and terraced	Poor	61	72	79	82
	Contoured and terraced	Good	59	70	78	81
Close-seeded legumes[1] or rotation meadow	Straight row	Poor	66	77	85	89
	Straight row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
	Contoured and terraced	Poor	63	73	80	83
	Contoured and terraced	Good	51	67	76	80
Pasture or range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
Meadow		Good	30	58	71	78
Woods		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		----	59	74	82	86
Roads (dirt)[2]		----	72	82	87	89
(hard surface)[2]		----	74	84	90	92

[1] Close-drilled or broadcast.

[2] Including right-of-way.

Source: Schwab, et al., 1966

range of plotted curve numbers for the chosen representative site. Condition II curve numbers found in Table 3.6 correspond to the numbers listed in the box at the upper right-hand corner of each CDF plot in Appendix A.

At this point, all of the necessary input data have been assembled and combined to choose a representative site number and to estimate the three key parameters; R, Ks, and CN. It should be stressed again that there is uncertainty in the reporting and/or estimation of these parameters. Most parameter values are reported as lying within a range or are expressed as a mean with a standard deviation. The example problems worked in Section 5 illustrate how these reported ranges can be utilized to enhance understanding and interpretation of methodology results.

3.4 FREQUENCY DISTRIBUTIONS

Once values of R, Ks, and CN are known, CDFs which correspond to these values are found by using the matrices at the front of Appendix A. The matrices are ordered by repesentative site numbers 1 through 19. Various site identification characteristics are listed first and the "address" matrix follows. This two-dimensional matrix includes retardation coefficient (R) values along the vertical axis and decay rate (Ks) values along the horizontal axis. The body of the matrix contains figure numbers which direct the user to the appropriate frequency distributions. Blank locations in the matrix are indicative of parameter combinations that result in no significant leaching.

The frequency distributions located immediately after the matrices in Appendix A contain leaching information relating a single value of R, a single value of Ks and four values of CN on each plot. The horizontal axis represents the percentage of the annual pesticide application that can be expected to leach per year. The vertical axis represents the percentage of time that the specified amount of pesticide leached will be exceeded. The following is a step-by-step example of how to locate and interpret the correct curves.

1. Assume that we are interested in a site located in northeastern Colorado planted in corn. Figure 3.3 shows that representative site #7 corresponds to this location.

2. We calculate input parameter values for R, Ks, and CN (e.g. R=1, Ks=.010, CN=80-85). Note that computed values of R, Ks and CN may not match exactly those found in the matrix. In this case a

value appearing in the matrix closest to that calculated is used.

3. Look at Figure 3.9a which contains the example "address" matrix used in locating the appropriate CDF. The matrices for all of the representative sites are located at the front of Appendix A.

4. According to the key parameter values from step 2, the corresponding frequency distributions can be found in Figure A7-3. Normally, a range of values for R and Ks would necessitate looking at several plots. The blank spaces in the matrix means that no significant leaching occurs for these combinations of R, Ks and CN values.

5. Figure 3.9b contains the example plot A7-3 with explanations of its format - the frequency curves are also found in the second part of Appendix A following the address matrices. For R=1, Ks=.010, and CN=85; there is, for example, a 10% chance that more than 40% of the applied pesticide will leach per year. For the same conditions, there is a 50% chance that more than 10% of the applied pesticide will leach per year.

Since the percentage leached is independent of application rate (See Section 4.3), the leached load can be expressed as the applied load times the percent leached. Thus, if 5 Kg-pesticide/ha were applied, there is a 50% chance that more than 0.5 Kg/ha will leach past the root zone in any given year.

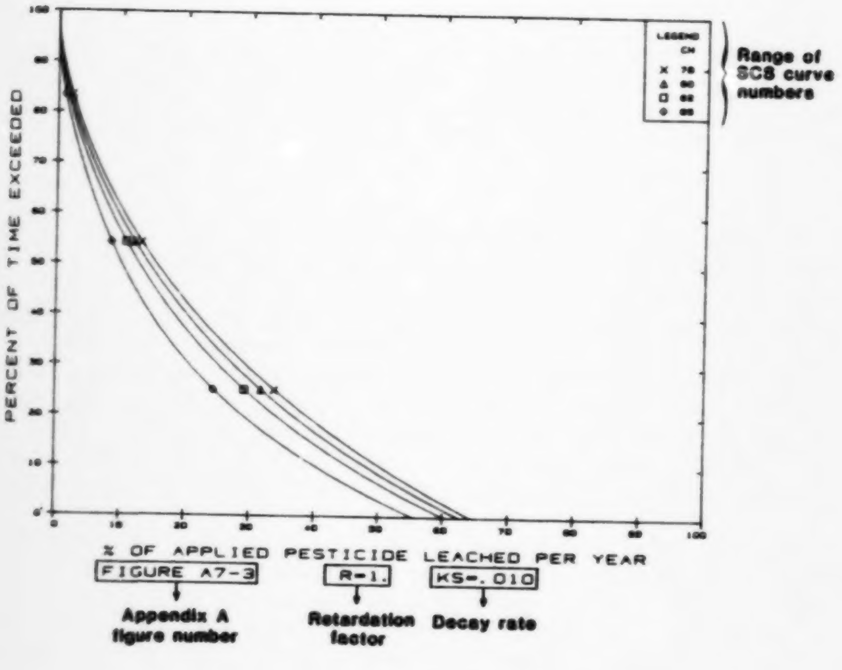
The family of curves represented on each plot defines the entire range of curve numbers used for each site. This range of curve numbers reflects the range of soil types and management practices reported in the SCS Engineering Handbook (U.S.D.A. 1971). In the above example, site 7 displays characteristic curve number values ranging from 78-85. This was deduced from the site descriptions defining the soil as part of Hydrologic Soil Group "C" and planted in a row crop,, corn. Different editions of the SCS Engineering Handbook report slightly different hydrologic soil group values.

Just as a single figure contains a range of four SCS Curve Numbers, a group of figures provides curves for a range of R or Ks values. For example, plots A7-1 through A7-4 describe the results of varying Ks values from .001 to .050. Likewise, curves found on plots A7-6 and A7-11 describe the results of varying R values from 3 to 5.

SITE NO. 7
CROP: CORN
CN: 78-85

R	Ks .001	Ks .005	Ks .010	Ks .050	Ks .100
1	A7-1	A7-2	A7-3	A7-4	A7-5
3	A7-6	A7-7	A7-8	A7-9	A7-10
5	A7-11	A7-12	A7-13		
20	A7-14	A7-15			
50					

Figure 3.9a Example Address Matrix



Range of SCS curve numbers

FIGURE A7-3 → **Appendix A figure number**

R=1. → **Retardation factor**

KS=.010 → **Decay rate**

Figure 3.9b Example Frequency Curve Plot

3.5 APPLICATION ASSUMPTIONS AND LIMITATIONS

The leaching frequency distributions in this handbook were created by applying PRZM under 19 idealized application scenarios. Various simplifying assumptions were made to reduce the number of computer simulation runs required for each representative site. The assumptions listed below pertain to PRZM input parameter selection. These assumptions are important to the interpretation of methodology results and may also affect applicability in certain situations. Limitations of the methodology are also listed below. These limitations are concerned with the overall approach rather than model specific limitations which are found in Chapter 4.

3.5.1 Assumptions

Soils

- A uniform soil profile was assumed from the surface to the crop rooting depth.
- A representative soil texture was chosen for each representative site - only the characteristics of a single soil type were input for that site.

Crops

- Representative crop rooting depths were chosen for each crop type and were the same for each site in which the crop is grown. The average values reported by Carsel, et al., (1984) were used. These values were for corn, soybeans, wheat and cotton; 90, 45, 22 and 60 cm, respectively.

Management

- One pesticide application per year was made each year of the simulations. The application was made just prior to the time of planting. There are many cropping patterns and pesticide application choices available. For instance, insect control in cotton may require foliar application several times during a growing season while weed control may be accomplished with one surface application prior to planting. The full range of possible combinations was too extensive to treat on a national scale. The majority of pesticides which would cause significant leaching problems are herbicides or fungicides applied prior to crop emergence, so an appropriate application date for each site was chosen. To best simulate actual application, conditions, the pesticide was applied at least two days following a rain event as well as at least two days prior to the next rainfall. This emulates a drying period following events sufficient to allow farm equipment use and a post application period reflecting the farmer's probable use of weather forecasts.

To test the validity of assuming a single pesticide application scenario, an analysis was performed on the effect of making a single annual application as opposed to 10 applications over a 100 day period. The results are displayed in Figure 3.10. It can be seen that the greatest discrepancy in pesticide remaining at the end of the 100 day period occurs in the middle of the range of probable decay rates. By applying pesticide continuously over this period, there will always be more chemical in the soil profile at the end of the 100 day period than if it is applied only once. This analysis does not address the question of how deep into the soil profile pesticide has traveled under the two application scenarios. This will depend on the meteorologic regime over the 100 day period. It can be assumed that the longer the pesticide is present in the soil, the further it will travel. In the cases where the decay rate is either very large or very small, little difference will be seen at the end of the 100 day period if application occurs once or at several times during the growing season. However in all three cases there is a discrepancy between pesticide available for leaching at the beginning of the 100 day period under the two different application scenarios. This effect disappears most quickly at high decay rates. Therefore, if the single application assumption is made and multiple applications are in fact used, at low decay rates actual pesticide leaching would be over-estimated while at high decay rates, leaching would be under-estimated.

- The assumption of the application of the pesticide each year has no impact on the frequency distributions for short lived chemicals. However, for chemicals that carryover from year-to-year, leaching would be overestimated. A single cutoff value of half-life (or decay rate) cannot be given because it changes with each representative site and value of Kd.

- One crop per year was simulated instead of using a rotation scenario.

- The same crop was simulated each year at each representative site.

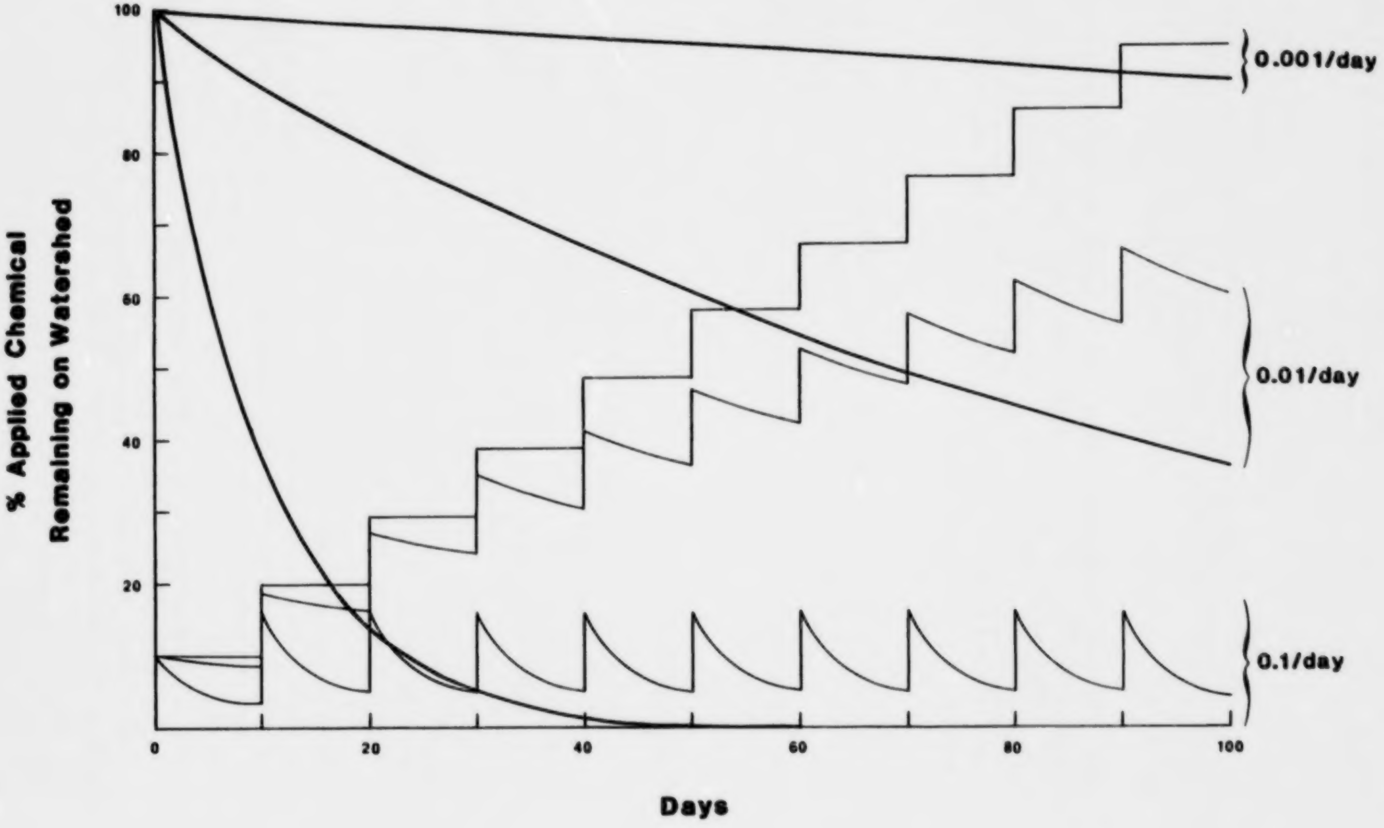


Figure 3.10 Comparison of Effects of Single and Multiple Pesticide Applications for Various Decay Rates

- The SCS curve number set after harvest of each crop was set at "residue" conditions to provide the worst case scenario (more infiltration occurring than under "fallow" conditions).

- Pesticide was surface applied rather than incorporated into the soil in the model. Pesticide incorporation would reduce those surface losses such as volatilization photolysis, and runoff. Therefore, lower overall model decay rates would be associated with subsurface incorporation.

  For foliar applications, the user should attempt to estimate the fraction of applied pesticide reaching the soil and multiply percentage leached results by this quantity. Note, however, that the quantity leached may be under-estimated due to washoff from the plant onto the soil.

Meteorology

- Representative sites 13 and 17 were the only ones with pan evaporation records complete enough for use. All other sites required synthesis of daily pan evaporation data by Hamon's formula, executed by PRZM.

3.5.2 Limitations

- The greatest limitation of this methodology concerns the application of single-valued characteristics to large representative sites. The handbook was devised as a screening tool for evaluating the potential for pesticide leaching to ground water. If site-specific characteristics would indicate more or less leaching potential than the representative site characteristics, further investigation may be necessary.

- Another major limitation is that available chemical data is both incomplete and imprecise. Reported values for Koc and Kow differ according to the reporting body. In many cases the coefficient of variation is over 100% of the mean value reported. The user may find that by taking the full range of reported values in estimating the three key parameters the entire range of parameters used in the methodology development will be spanned. In this case, the user should strive to narrow the uncertainty in his input data and re-evaluate.

- Because PRZM utilizes the runoff curve number approach, little practicable sensitivity analysis can be performed by the user in terms of altering specific management practices. Only major changes in management such as contouring to terracing can be examined.

SECTION 4

METHODOLOGY DEVELOPMENT

4.1 INTRODUCTION

The following section explains the four basic steps taken to compile this handbook. First, a suitable model was selected. Second, those model parameters most important to the production of pesticide leachate were determined. Third, representative agricultural sites were chosen. Finally, production runs were made to generate the distributions for each site.

4.2 MODEL SELECTION

Several models are currently available which simulate the migration of organic contaminants through porous media. In order to evaluate the available models in terms of their suitability for this project, the following objective review criteria were developed:

- The model should be capable of simulating the leaching of organic compounds (with important loss mechanisms).
- Important chemical and soil parameters should be easily changed.
- A variety of structural and nonstructural management practices should be capable of being simulated.
- The model should require readily available data as inputs and should have no parameters which require extensive calibration.
- The model must be a working computer code, fully documented.

- The model should be based on acceptable theory and utilize sound solution techniques.

- The model should be one-dimensional or easily collapsed to one dimension.

A survey of available models was used to start the selection process. A very good survey was done recently by Oster (1982). In that report he reviewed 55 different models for flow and solute transport in the unsaturated zone. Of these 55, ten flow and transport models were selected on the basis of documentation, applications and availability of the code. Of these ten, three are purely flow models. The remaining seven were:

1) SEGOL (Segol, 1976)
2) SUMATRA-1 (van Genuchten, 1978)
3) TARGET (Sharma, 1979)
4) FEMWATER/FEMWASTE (Yeh and Ward; 1979, 1981)
5) TRUST/MLTRAN (Reisenauer, et al., 1981 and 1982)

The SEGOL model is two or three-dimensional and cannot be collapsed to one-dimension. As such it likely would be overly expensive to run and overly detailed for this application.

SUMATRA-1 is a one-dimensional finite element model that simulates flow and solute transport under transient saturated/unsaturated conditions. The strengths of this model are its apparently stable and accurate solution technique, its ability to simulate temporarily saturated and unsaturated percolation and abruptly changing soil profile properties. It considers linear adsorption and zero or first-order decay of the solute.

TARGET is a proprietary code owned by Dames and Moore and performs simultaneous hydrodynamics, solute transport and heat transfer. It is a three-dimensional model and thus its use was not justified given the scope and intent of this study.

FEMWATER/FEMWASTE is a two-dimensional finite element model. It includes dispersion, advection, adsorption and decay of the chemical species but does not consider surface hydrologic processes or evapotranspiration.

TRUST/MLTRAN is either a one or two-dimensional nondispersive kinetic transport model. The output is highly dependent upon graphic displays.

None of the above models were developed with the simulation of agricultural applications in mind. Most require boundary conditions at the soil surface which would have to be obtained from a surface hydrologic model. Therefore none have the innate capability to simulate the effects of management practices upon leaching. Of those reviewed by Oster, SUMATRA-1 looks most applicable to the problem.

Two models available but not reviewed by Oster are PRZM, developed by the U.S. EPA at Athens, GA, (Carsel et al., 1984) and PESTAN (Enfield et al., 1982), also developed by the U.S. EPA at the RSK Environmental Research Laboratory in Ada, OK.

PESTAN is a steady flow model using a constant pore water velocity and thus cannot be used effectively to develop frequency curves for pesticide leaching.

PRZM is a one-dimensional finite difference model for solute transport under unsaturated conditions. It includes a hydrologic model which utilizes the SCS runoff curve number approach to generate infiltration rates for the transport model. Therefore, the effects of agricultural management practices can be simulated by selecting curve numbers, and little or no calibration is required. Because of assumptions made in the hydrologic model, transient saturated conditions cannot be simulated and, therefore, the solution technique is deemed accurate only on soils that are well drained. It is on these types of soils, however, that leaching is more likely to be a problem. As a whole, this model is best suited to the scope of this project primarily because it is linked to the curve number approach for surface hydrology to supply infiltration volumes, and can also be operated quite inexpensively for long simulation time periods.

4.3 SENSITIVITY ANALYSIS

Once the model was chosen, sensitivity analyses were performed with PRZM for three purposes:

- To choose the key parameters of primary importance to pesticide leaching,
- To assign meaningful ranges for these parameters, and,
- To determine an appropriate length of simulation period (i.e., a length of time sufficient to provide a stationary mean for frequency distributions).

Approximately 500 model runs were made, some of 25 year durations. Before the tests were performed, critical test parameters and associated ranges were established.

There are two categories of parameters that affect the amount of pesticide that will leach below the crop root zone. They will be referred to as transport parameters and supply parameters. Transport parameters affect the movement of contaminants in the soil, while supply parameters govern the quantity of contaminant present. Table 4.1 lists the transport and supply parameters important to PRZM, along with their associated ranges of values.

The range of values for each parameter is indicative of upper and lower limits found for agricultural soils and chemicals in current production. The 500 model test runs allowed for comparison of the relative importance of each parameter, within its established range, to pesticide leaching.

The relative effect of each transport and supply parameter is governed by the mass balance/transport equation used in PRZM (Carsel, et al., 1984):

$$\frac{\partial Cw}{\partial t} = D \frac{\partial^2 (Cw/R)}{\partial z^2} - \frac{\partial (Cw\ V/R)}{\partial z} - (Ks+U)Cw \qquad 4.1$$

where the transport parameters are:

- R, the retardation factor
- D, the dispersion/diffusion coefficient
- V, the pore water velocity

and the supply parameters are:

- Ks, the pesticide decay rate, and
- U, the plant uptake rate.

Cw, is the dissolved pesticide concentration, t is time and z is depth in the soil profile.

The retardation factor, R, is defined as:

$$R = 1 + \frac{(Kd)\ (\rho s)}{\theta} \qquad 4.2$$

Since Kd = Koc(OC)/100, then,

$$R = 1 + \frac{Koc\,(OC)\,\rho s}{100\theta} \qquad 4.3$$

Koc is a property of the pesticide while OC and ρs are properties of the soil. Koc for many compounds are given by

TABLE 4.1 PARAMETERS, AND THEIR RANGES, CHOSEN FOR SENSITIVITY TESTS

CATEGORY	PARAMETER	DEFINITION	UNITS	RANGE
Transport	R K_d	Adsorption Partition Coefficient	cm^3/g -soil	$0.0-10^3$
	ρ_s	Soil Bulk Density	g/cm^3	0.9-1.8 [1]
	V θ_{fc}	Field Capacity Water Content	cm^3/cm^3	4-26 [2]
	θ_{wp}	Wilting Point Water Content	cm^3/cm^3	1-17 [2]
	P	Precipitation	cm	50-150
	CN	Runoff Curve Number	-	51-94
Supply	TAPP	Pesticide Application Amount	Kg/ha	.25-20
	K_s	Pesticide Decay Rate	/day	$2.0\times10^{-4}-10^{-1}$ [3]

[1] Baes and Sharp (1983)

[2] Rawls (1982)

[3] Nash (1980)

Rao and Davidson (1980). These values range from 2 to 2x10**6 with coefficients of variation ranging from 10 to 130%. Brady (1974) gives ranges of organic matter from 0.1 to 15.1%. Using a conversion factor of 1.7 for % organic matter to % organic carbon, OC, this range becomes 0.05 to 9.0%. Bulk density varies with a number of factors including depth in the profile. Baes and Sharp (1983) report values of roughly 0.9 to 1.8 g/cc. The field capacity and wilting point moisture contents reported by Rawls (1982) for each soil textural class were used as limits on θfc and θwp.

Molecular diffusion is only important at low water velocities (Freeze and Cherry, 1979) and so it was ignored in the sensitivity analyses. According to the developers of PRZM, with a compartment (i.e., soil layer) depth of 5 cm and temporal timestep of one day, the numerical dispersion in PRZM approximates actual dispersion observed in the field. Therefore, the diffusion/ dispersion parameter, D, was set to zero. The pore water velocity is affected by the same parameters that affect θ and, in fact, is a function of θ. Therefore, no sensitivity analyses were performed using V directly.

Of course, V is affected by relative rates of rainfall and evapotranspiration. For the analysis, 25 years of daily rainfall and evaporation data were obtained for Macon, GA. It was felt that this site, having high intensity rainfalls and sandy soils would show more pronounced sensitivity to other parameters. Infiltration depths were varied by manipulating runoff curve numbers from 51 to 94, encompassing the complete range of A to D soils planted in row crops or small grains (Schwab, et al., 1966).

Notwithstanding the usually small quantities lost in runoff and erosion and the amounts transported from the soil profile, the amount of pesticide in the profile depends upon the application rate, and Ks and U in the mass balance equation. Pesticide application rates generally vary between 0.25 to 20.0 Kg/ha according to Nash (1980). Because U and Ks both multiply Cw in the pesticide advection/dispersion equation, the sensitivity of the output to each is equivalent. Therefore, only Ks was varied in the sensitivity tests. Ks is the lumped first-order decay rate which represents the decay process. Typical rates vary from about .0001 to 2.9/day (Nash, 1980).

The transport and supply parameters chosen above for further investigation were varied both individually and in combinations to find their individual and synergistic effects on pesticide movement. Through sensitivity analyses, the most influential parameters were found and the range of values most important to frequency curve production defined.

The following are the major qualitative results of the analyses:

- One of the major findings of the sensitivity tests was that climatic factors and pesticide properties seem to be more important factors in determining leaching losses than properties of the soils.

  Other specific conclusions are:

- The chemical specific organic carbon (or octanol/water) partition coefficient, Koc (or Kow) is the most important parameter that determines the mobility of the compound. This is primarily due to the extremely large range of possible values for the coefficient.

- Remaining variables that are important include:
  - Rainfall amount and timing,
  - Decay rate,
  - Soil organic carbon content,
  - Bulk density, and
  - Runoff curve number.

  However, the sensitivity of these parameters can change significantly at various levels of the partition coefficient. For instance, when Koc is large, the sensitivities (partial derivatives) of the model output (% of applied pesticide leached below the root zone) to ρs, %OC, and curve number go to zero. When Koc → 0.0, the sensitivity of ρs and OC% also go to zero, but curve number attains its maximum sensitivity. Thus, ρs and OC% are sensitive only at intermediate values of Koc. This is illustrated for the case of bulk density in Figure 4.1. The fact that the sensitivity to runoff curve number goes to zero as Koc becomes large is demonstrated in Figures 4.2 through 4.4. Notice that the amount of pesticide leached is lower and that the random behavior of the output is damped out as Kd (or Koc) increases. The effect of runoff curve number also decreases as decay rate goes to zero, i.e., half-life becomes long.

- The time required for a chemical to attain a "steady-state" mean soil concentration is a function primarily of Koc (or Kd). In these analyses, even at half-lives of two years, a steady-state mean was achieved in about seven years. Figure 4.5 shows how increases in Kd resulted in lower mean output and time to achieve steady-state was lengthened. Figure 4.6 shows that increasing decay rate also lowers the mean output, but shortens the time to steady state. The mean annual precipitation rate over this 23 year period was 115 cm. For long half-lives and high Kd, carryover effects must be considered. Non-zero pesticide concentrations can be used as initial conditions for the simulations.

- The percentage of applied pesticide leached below the root zone is independent of the quantity applied in PRZM. In our tests, 100, 1000, and 10,000 g/ha were applied. No differences were observed in the percentage leached. Consequently, a unit application rate was used in developing the methodology. In reality, adsorption/desorption isotherms for pesticides in soils can be non-linear. If this happens, then the

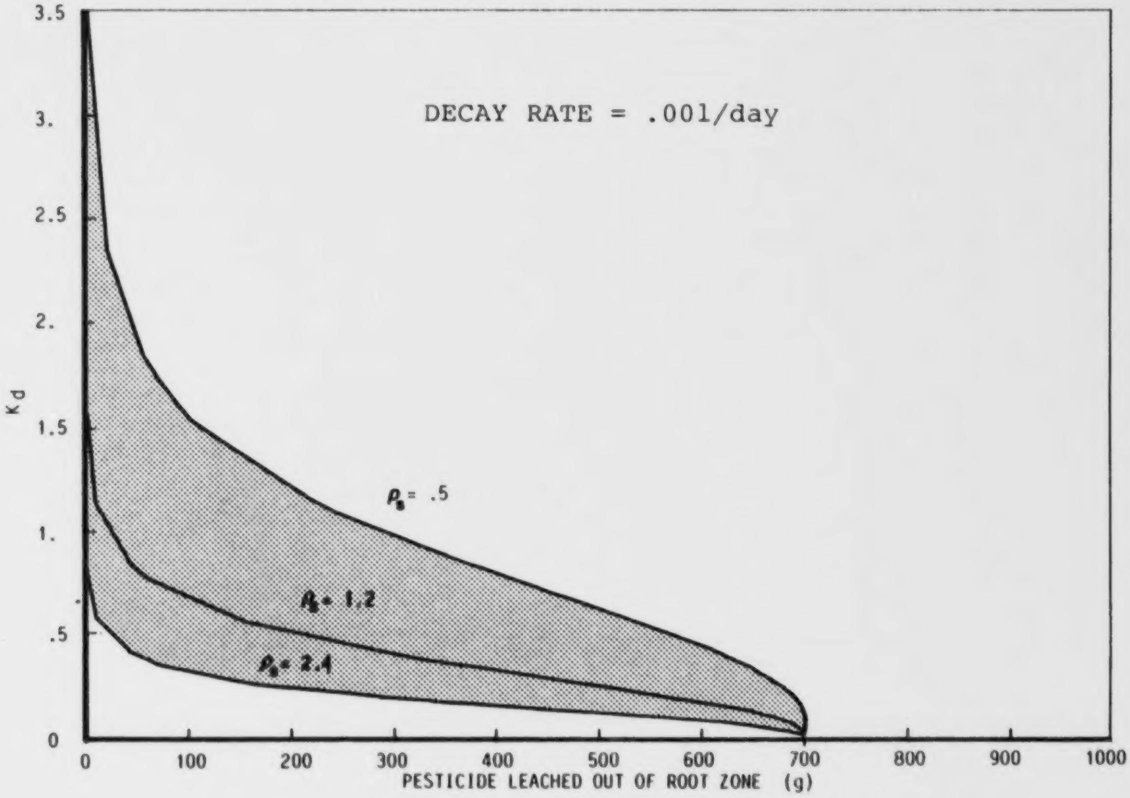


Figure 4.1 Effect of Kd and ρs on Quantity of Pesticide Leached

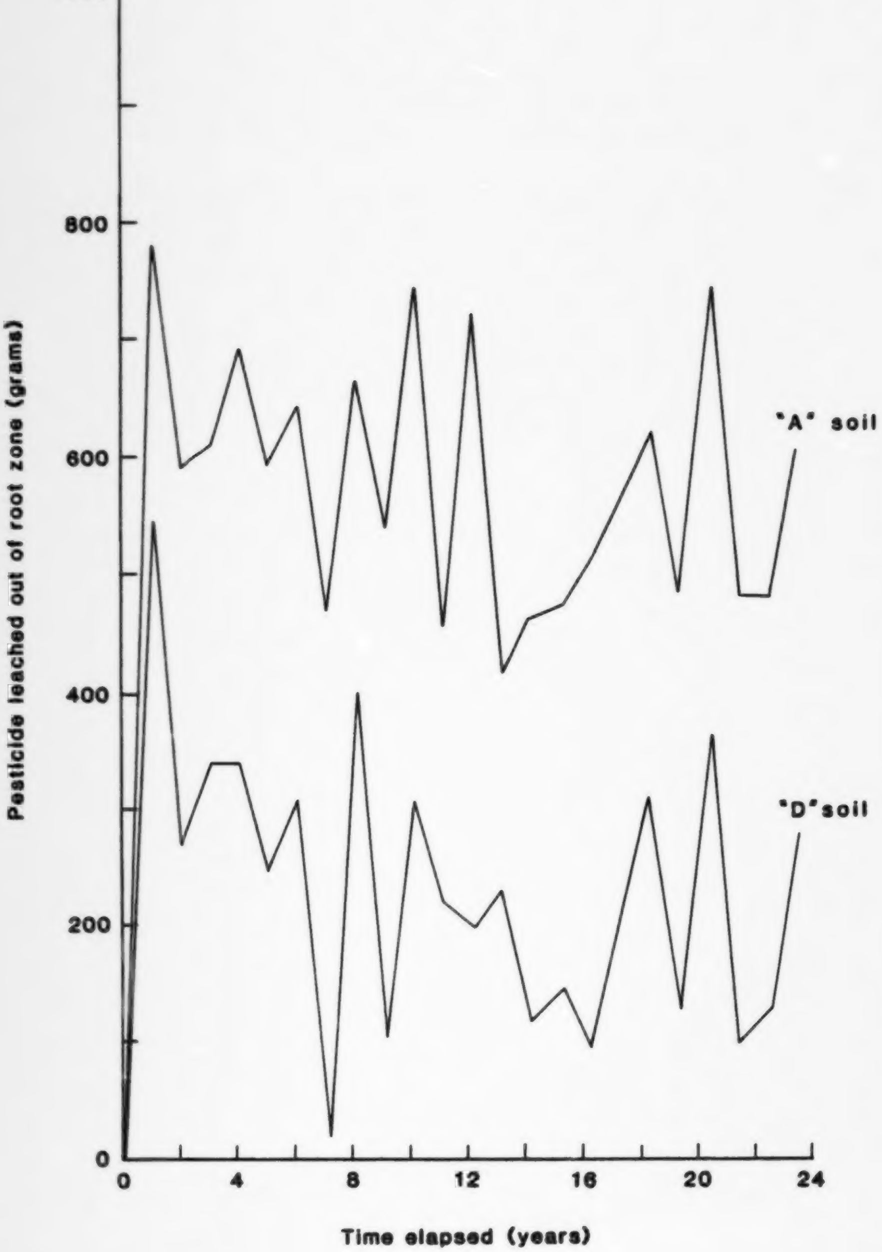


Figure 4.2 Effect of SCS Curve Number on Annual Pesticide Leached (Kd = .06)

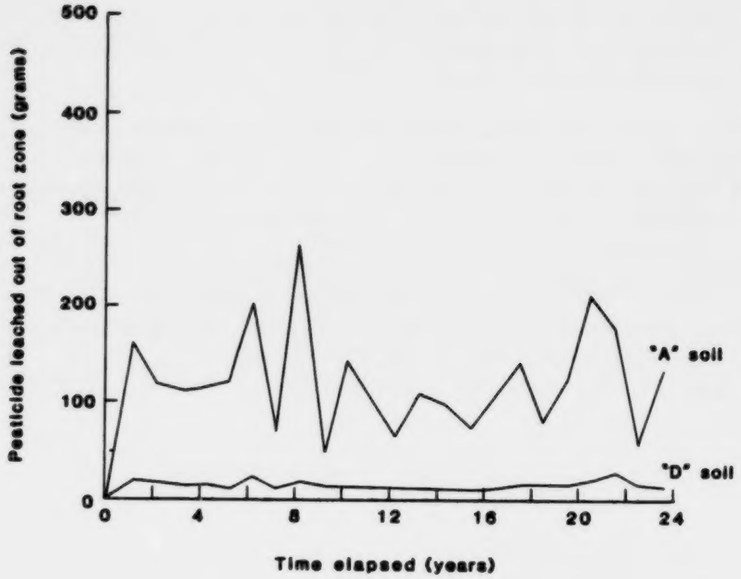


Figure 4.3 Effect of SCS Curve Number on Annual Pesticide Leached (Kd = 0.6)

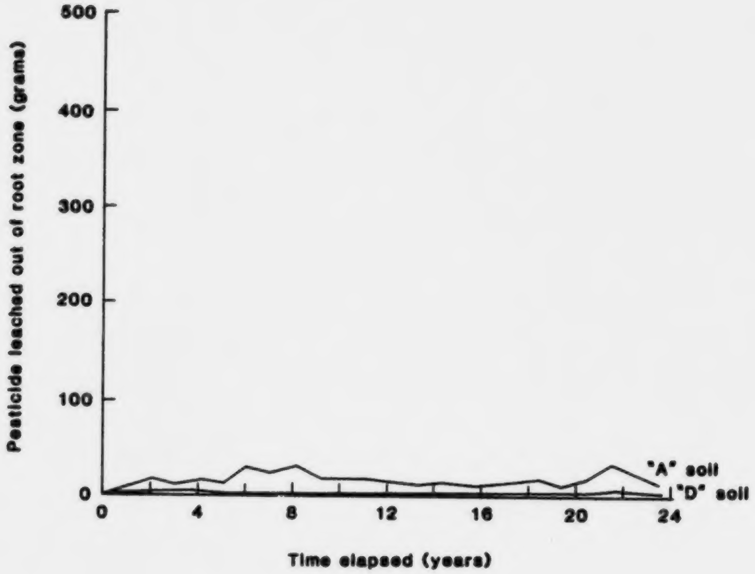


Figure 4.4 Effect of SCS Curve Number on Annual Pesticide Leached (Kd = 1.5)

> percentage leached will not be independent of the load. However, if concentrations in the soil are low (as they would be in agricultural applications) linearity can usually be assumed without introducing substantial error.

The major problem with producing frequency distributions for each region was to determine the least number of parameters that could be used to describe the leaching phenomenon and to select ranges of these parameters, and levels within these ranges, to characterize the system. From the results of the sensitivity analysis it was learned that, at a minimum, Ks, ρs, OC, Koc, θfc, and CN must be considered. The remaining important parameters, precipitation, evapotranspiration, and depth of root zone were fixed by selection of location and crop type. Variations in rainfall amount and timing were

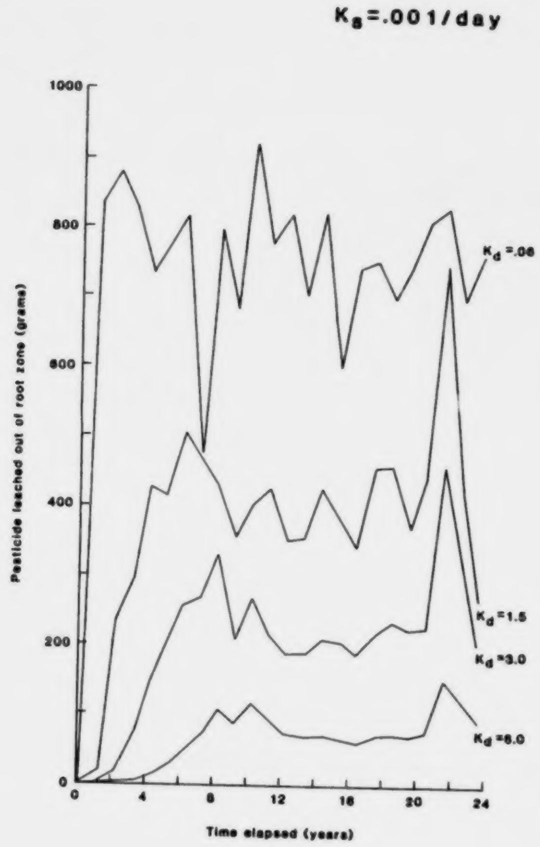


Figure 4.5 Effect of Kd (cm^3/g) on Time to Reach Steady-State Mean Annual Output

factored in by using a long period of record at each site chosen for analysis. Fortunately, ρs, OC, Kd and θfc, can be combined into R, the retardation factor, leaving only three parameters to vary for each site.

Although the format and presentation of the frequency curves are simplified by the use of 3 parameters, all of the input factors listed earlier are important. The production of leachate is most sensitive however to fluctuations in the retardation factor, curve number and decay rate and the consideration of these parameters is adequate for screening purposes at a particular site. The actual ranges of model parameter values chosen to produce the frequency curves were distilled from those ranges reported in Table 4.1. Five values of R; 1, 3, 5, 10 and 50 and five values of Ks; 0.001, 0.005, 0.01, 0.05, 0.1 were chosen to represent the spectrum

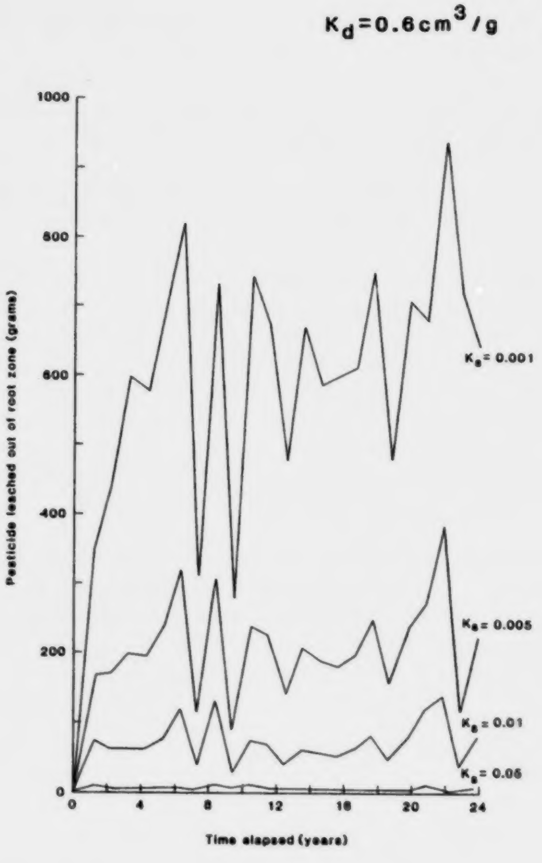


Figure 4.6 Effect of Decay Rate (/day) on Time to Reach Steady-State Mean Annual Output

of problematic compounds. Four values of curve number appropriate to the soil/crop/management scenarios at each site were also used.

For the majority of cases, leaching of pesticide was shown not to be a potential problem. Only small values of R resulted in significant leachate production, while the entire range of observed Ks and CN values affected leaching potential. Regardless of hydrologic regime or half-life, values of R greater than 50 produced no significant leaching over a 25 year period. This eliminates concern over leaching for a majority of pesticides on the market today.

The final purpose of performing sensitivity analyses was to determine an appropriate length of simulation period. A period of 25 years was chosen for three reasons;

- steady-state mean output is achieved for most compounds within this time frame,
- known meteorologic periodicities are likely to fully cycle during that period, and
- few stations have concurrent precipitation and evaporation data for more than 25 years.

During the production of frequency curves, if the leaching of pesticide was significantly different in the first five years than in the last 20 years, an initial pesticide level equal to the remaining pesticide level after the 25 year simulation was input and the entire simulation was rerun. This was done to provide a stationary mean and variance in the frequency distributions. Thus, the variation in annual percentage leached in any individual distribution is solely a function of natural variations in climate.

Note that the intention here is not to make a statement about the total quantity of pesticide leached over the 25 year period, but to provide a probabilistic estimate of the amount that may move past the root zone once a quasi "steady state" concentration profile is reached in the soil.

4.4 REPRESENTATIVE SITE SELECTION

The four most economically important crops in the U.S. were chosen to define areas of potential pesticide leaching. These crops - wheat, corn, soybeans, and cotton - are grown extensively throughout the country under a wide range of soil characteristics, meteorologic regimes, and pesticide application scenarios. The most widespread pesticide leaching problems would likely arise in conjunction with usage on one of these crops.

The method chosen for delineation of the 19 representative sites involved the transfer of agricultural, meteorologic, soils, and pesticide usage information to national maps. Each map contains the boundaries of a single characteristic of interest and was overlayed with other maps to discover naturally occurring spatial relationships. The major crop growing areas of the U.S. are delineated in the 1978 Census of Agriculture (U.S. Dept. of Commerce, 1982). The boundaries of the major growing areas for wheat, corn, soybeans, and cotton were transferred to four national maps (Figures 4.7 - 4.10). Areas in which irrigation is essential for crop production were eliminated from further consideration. Precipitation isopleths in 10" (25.4 cm) increments were also drawn on a map (Figure 4.11). Likewise, maps of the hydrologic soil groups and major areas of herbicide and insecticide usage were produced (Figures 4.12 - 4.14). The final representative site delineations were drawn onto four maps, each one corresponding to a single crop. These were previously displayed in Figures 3.2 to 3.5.

Nineteen sites were delineated in this fashion. After they were chosen, site-specific data were gathered for each site to satisfy input requirements for PRZM. Table 4.2 lists meteorologic, soils, and crop data used which describe individual sites. Information from Tables 3.1, and 4.2, was combined to produce input parameter values for PRZM.

The meteorologic stations chosen to represent precipitation, evaporation, and temperature conditions at each site were selected from a data base developed by EPA-Athens staff using data provided by the National Center for Atmospheric Research. The station records were required to contain a minimum of 25 years of continuous daily values, with as few missing entries as possible. Average annual rainfall for the chosen 25 year period was compared to the site description chosen earlier to check for compatability (Table 3.1). If more than 25% of the evaporation data were missing, PRZM internally calculated daily values using Hamon's method. This method was used in all cases except one (Station 1726, South Carolina), primarily because during the winter months few stations make evaporation measurements. Missing temperature data were generated by averaging other values on that day over the 25 year period. This method was chosen, as opposed to interpolation, because many gaps extended longer than just a few days (sometimes a month or more data were missing). The meteorologic station numbers, the chosen time periods, and average annual precipitation and temperature values for each site are also listed in Table 4.2.

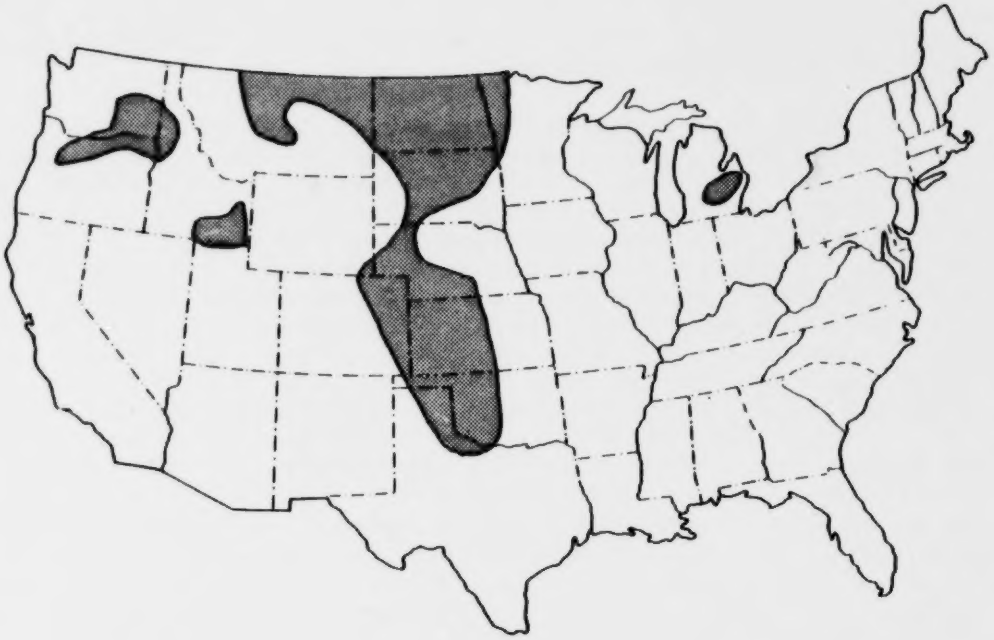


Figure 4.7 Major Wheat Farming Regions of the U.S.
Source: U.S. Dept. of Commerce, 1982

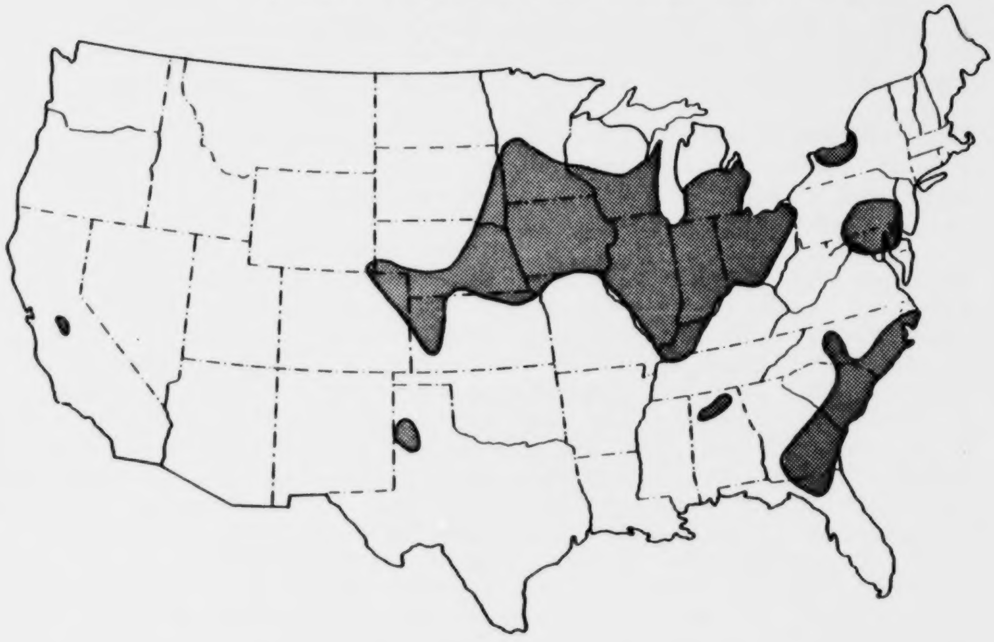


Figure 4.8 Major Corn Farming Regions of the U.S.
Source: U.S. Dept. of Commerce, 1982

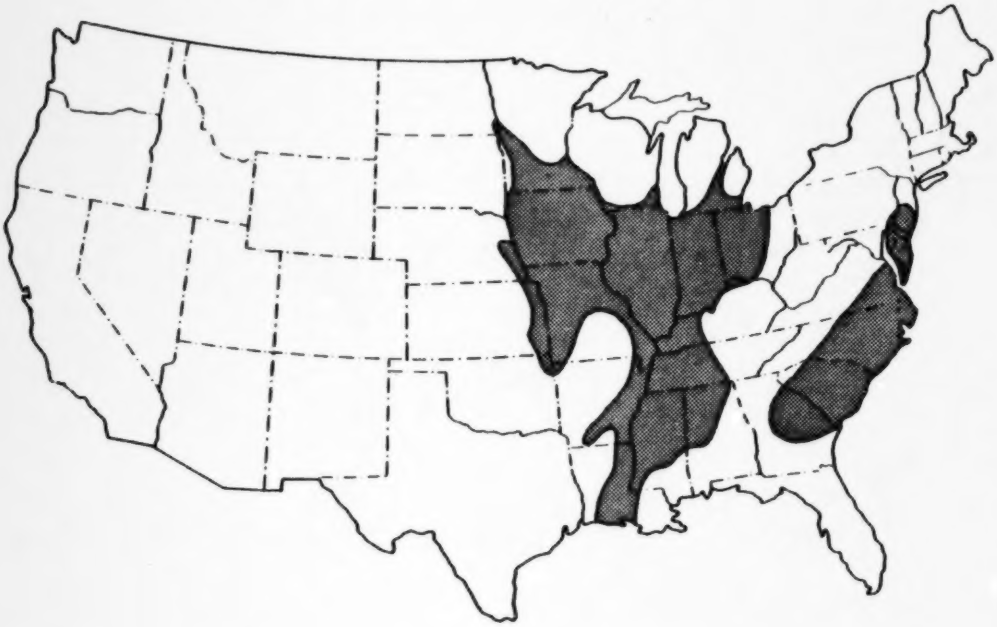


Figure 4.9 Major Soybean Farming Regions of the U.S.
Source: U.S. Dept. of Commerce, 1982

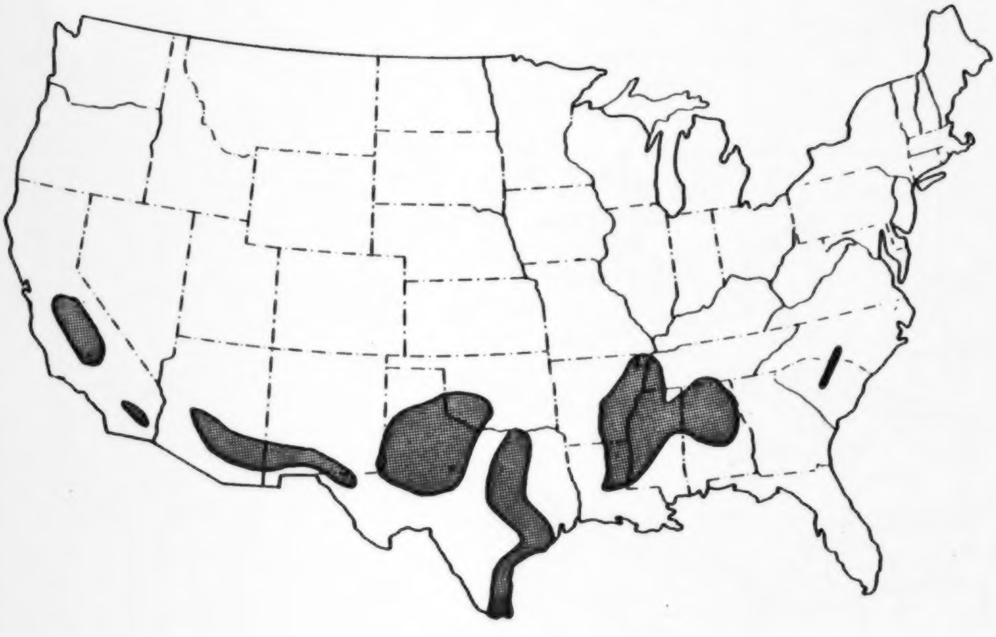


Figure 4.10 .Major Cotton Farming Regions of the U.S.
Source: U.S. Dept. of Commerce, 1982

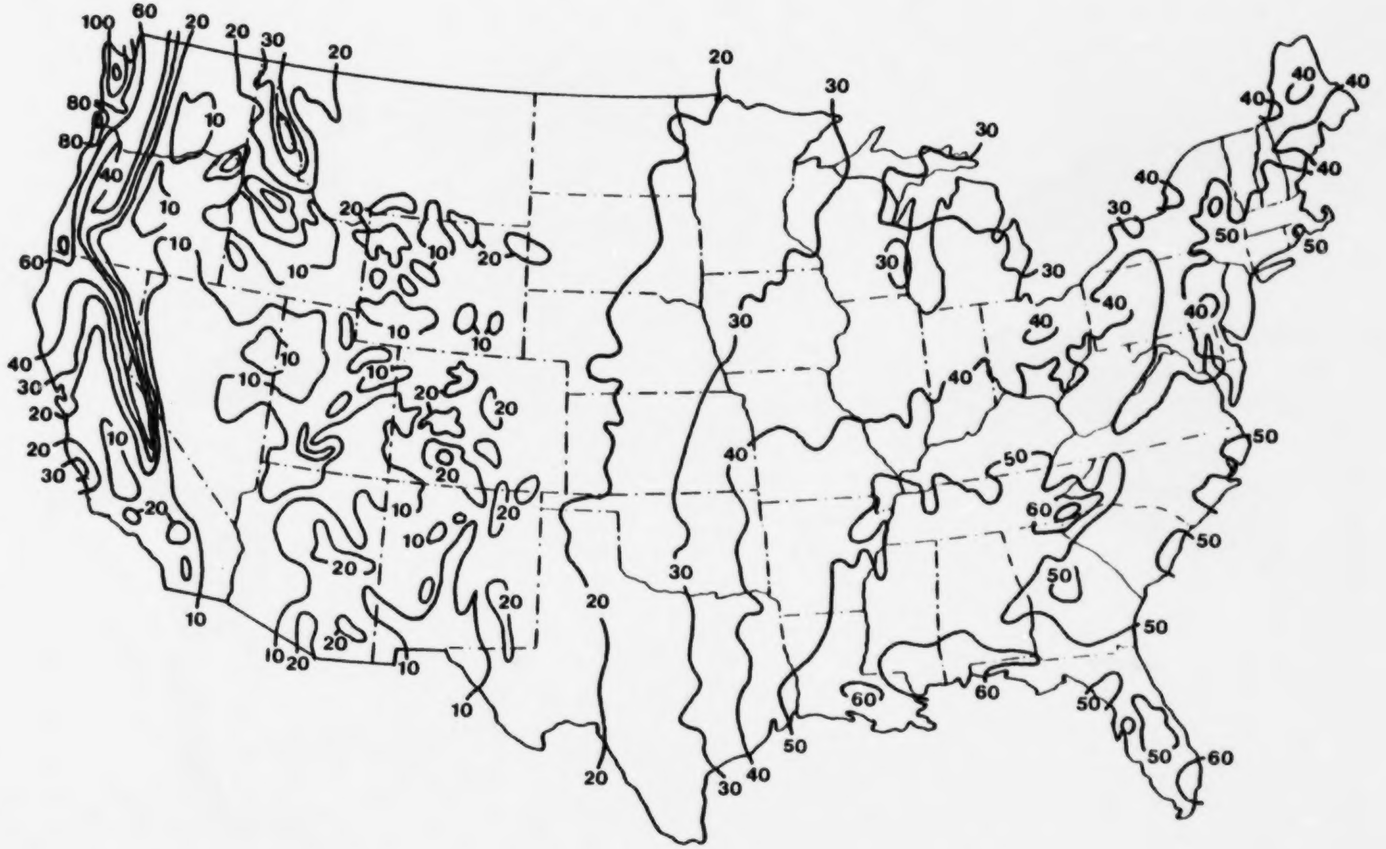

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Figure 4.11 Average Annual Distribution of Precipitation
Source: Geraghty, et al., (1973) (1"= 2.54 cm)

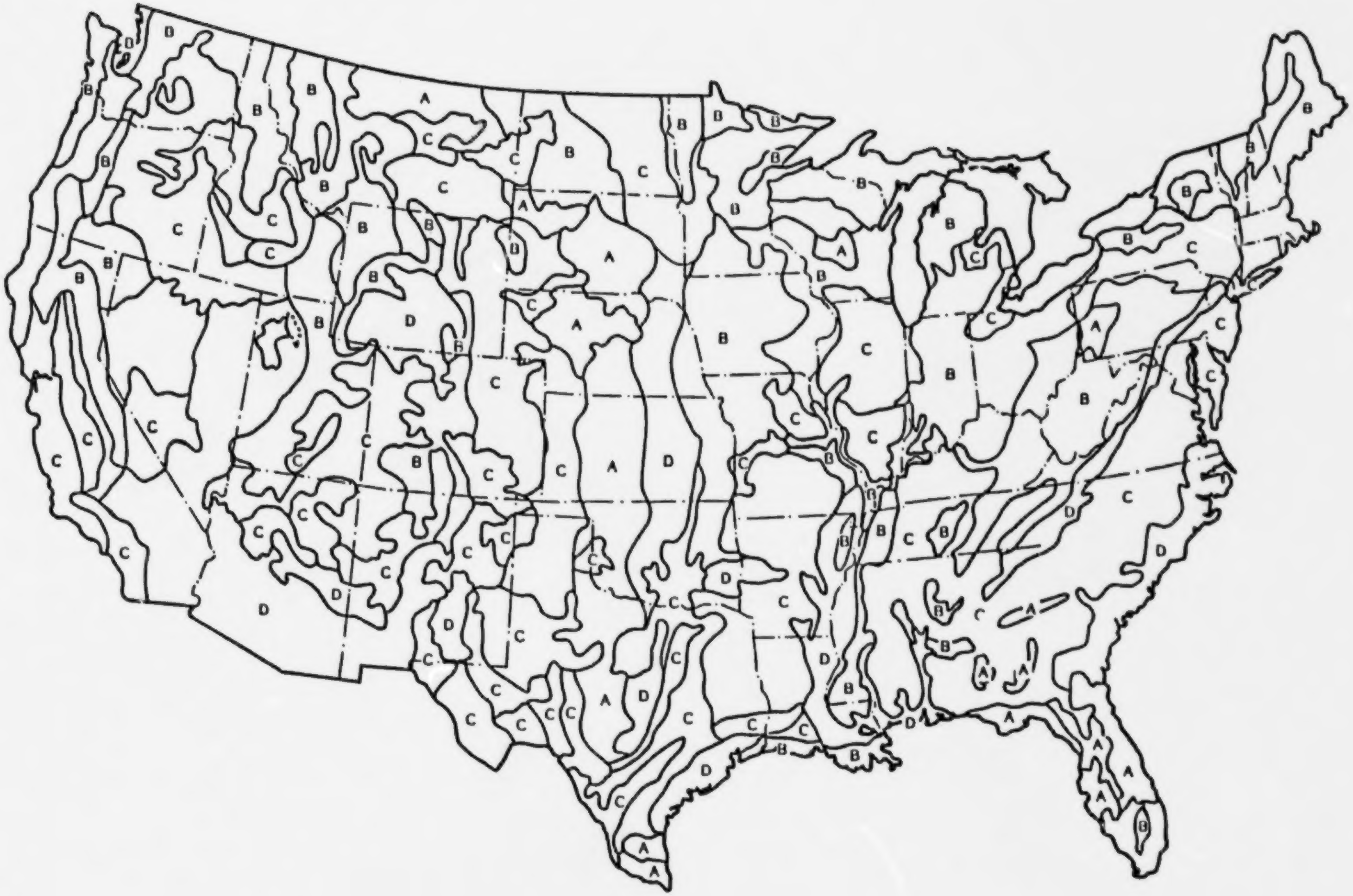


Figure 4.12 Generalized Hydrologic Soil Groups for the U.S.
Source: Battelle (1982)

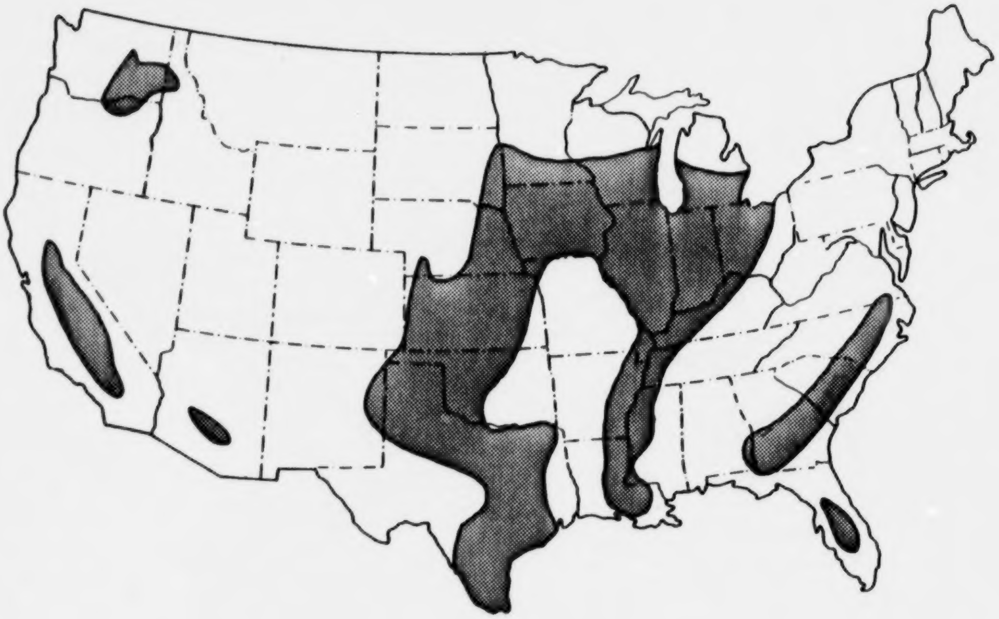


Figure 4.13 Major Regions of Insecticide Usage in the U.S.
Source: U.S. Dept. of Commerce, 1982

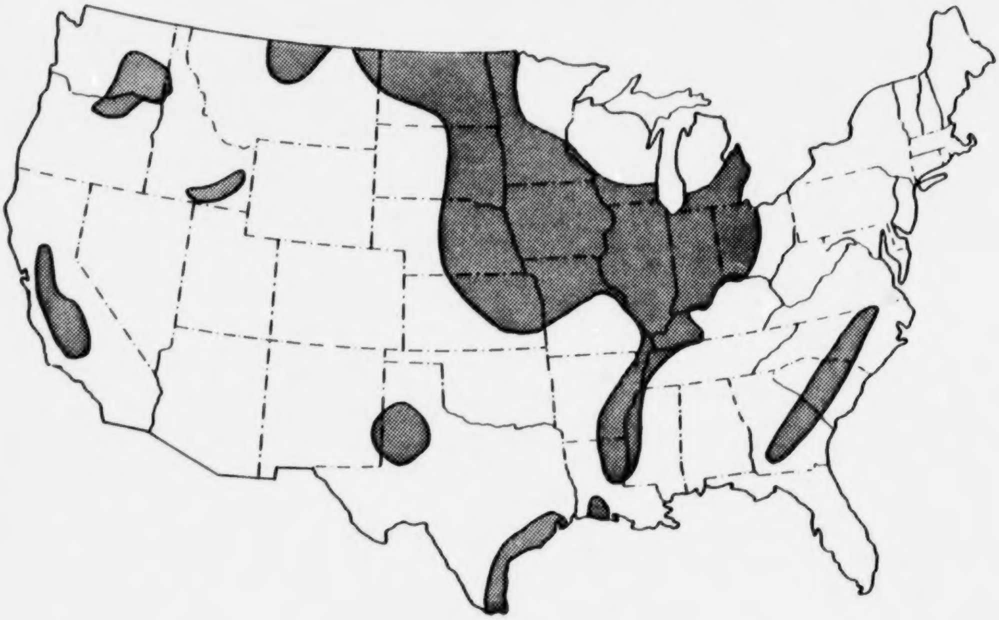


Figure 4.14 Major Regions of Herbicide Usage in the U.S.
Source: U.S. Dept. of Commerce, 1982

SCS county soil surveys were used to further define soils characteristics at each site. For each site three or four surveys were randomly selected; the soil textures listed, and their respective areas summed. In most cases a single soil type was consistently prevalent within a site. If more than one soil type was prevalent the soil having the largest areal coverage was chosen. Soil textural classifications for each site are also listed in Table 4.2. These textures were used to determine field capacity (θfc) wilting point (θwp), and bulk density (ρs) input values for PRZM.

Crop information was also determined by consulting SCS soil surveys, Carsel et al.,(1984), and Agricultural Handbook # 283 (U.S.D.A. 1972). The planting and harvest dates for the major crop of each site are also listed in Table 4.2. The plant rooting depth was taken as the average of the range reported by Carsel et al., (1984).

4.5 FREQUENCY DISTRIBUTION PRODUCTION

After selecting a model, choosing the appropriate range of input parameter values, and choosing the representative agricultural application sites, the final step was to make the simulation runs required to produce the frequency curves in Appendix A. One hundred runs of 25 years duration were made for each site, resulting in 2500 simulation years per site. The frequency distributions in Appendix A are a compilation of nineteen multiples of these runs, or 47500 simulation years. The simulations were made on an HP-1000 micro-computer, requiring approximately seventeen hours of run-time per site.

TABLE 4.2 SOILS, CROPS AND METEOROLOGICAL CHARACTERISTICS OF REPRESENTATIVE SITES

Site	State/Station #	25-Year Test Period	Annual Precip (in)	Annual Temp (°C)	Predominant Soil Type	Planting Day(Julian)	Harvest Day(Julian)
1	WA 8926	1/37-12/61	15.5	12.1	Silt Loam	79	227
2	ID 10	1/54-12/78	22.6	7.4	Silt Loam	125	237
3	MT 3110	1/54-12/78	11.6	7.6	Loam	121	232
4	ND 5479	1/48-12/72	15.6	6.9	Loam	121	227
5	NE 4455	1/54-12/78	18.2	10.8	Sandy Loam	262	215
6	KS 1383	1/50-12/74	20.9	12.1	Loamy Sand	262	215
7	CO 834	1/54-12/78	16.3	10.6	Loamy Sand	129	305
8	NE 3395	1/54-12/78	23.2	10.6	Silty Clay Loam	132	305
9	IL 8179	1/54-12/78	34.5	11.9	Silt Loam	136	305
10	MI 7690	1/54-12/78	34.6	9.4	Loam	136	275
11	OH 1466	1/54-12/78	36.1	9.2	Silt Loam	139	305
12	MD 700	1/54-12/78	40.5	12.0	Silt Loam	140	280
13	SC 1726	1/54-12/78	47.1	16.7	Sandy Loam	105	295
14	IA 205	1/39-12/63	31.7	9.8	Silt Loam	152	288
15	MS 1707	1/54-12/78	50.4	17.1	Silt Loam	152	305
16	IN 6506	1/54-12/78	40.8	11.1	Silt Loam	140	283
17	SC 1726	1/54-12/78	47.1	16.7	Sandy Loam	152	319
18	IA 1411	1/54-12/78	50.4	17.9	Silt Loam	105	263
19	AL 5140	1/49-12/73	52.1	17.7	Sandy Loam	105	263

1" = 2.54 cm

SECTION 5

EXAMPLE APPLICATIONS

This section contains two example problems. They are presented to help guide the user through test cases from start to finish. The first example presents a simple, straight-forward case without complications. The second example explains the use of the handbook when available data does not conform exactly to the format presented. These two examples strive to cover most situations where this handbook procedure is applicable and offer insightful discussion of the results, assumptions and limitations.

5.1 EXAMPLE #1

In this example application we will assume that the pesticide aldicarb is hypothetically being applied to soybeans in the delta area of Mississippi. We wish to know if the continued annual application of the pesticide to this crop will result in leaching of aldicarb below the crop rooting depth.

Step 1: Choose site: Columbus, MS
long. 88° 30' lat. 33° 30'
Crop : soybeans
Pesticide : aldicarb

Step 2: Calculate input parameters for locating frequency distributions (R, Ks, CN)

Retardation Factor (R)

a) Look up Koc, Kow, or S value for Aldicarb: from Table B-3 in Appendix B, Kow = 5.00

b) If Koc is not reported, it must be computed from Kow or S:
from Table 3.2 eq. 4.
log Koc = .544 (log Kow) + 1.377
log Koc = .544 (log (5.00)) + 1.377 = 1.7572
Koc = 57.2

c) Determine organic carbon (OC) in soil from reported values or calculate as follows:

From national soil nitrogen survey, Figure 3.6
N = 0. to .05% and
OC = 11*N
therefore OC = 0. to .55%

d) Determine bulk density (ρs) from the soil textural classification, if known. If texture is not known use that listed for the representative site; Columbus, MS is within site #15 and the predominant soil texture is silt loam (from Table 4.2)

ρ silt loam = 0.86 to 1.67 (from Table 3.3)

e) Determine field capacity (θfc) from field values, reported values, or regression equations.

θfc, silt loam = .258 to .402 (from Table 3.4)

f) Calculate R (equation 3.1):

$$R_{low} = 1 + \frac{57.2\ (0.0)\ (1.17)}{0.402} = 1.0$$

$$R_{high} = 1 + \frac{57.2\ (0.0055)\ (1.67)}{0.258} = 3.0$$

Note: a single value of Kow was reported for aldicarb. There is uncertainty about this value that is not reported in Appendix B. Further investigation is warranted if a more representative range for R is desired.

Decay Rate (Ks)

Ks must be found in the literature. Some values are reported in Appendix B.

Ks for aldicarb = .03695 with a coefficient of variation of 103.8% (Table B-6, mean of 5 values) therefore, Ks = 0.0 to 0.0753

This spans nearly the entire range of values in the address matrices for Ks. The user may want to gather more information specific to the soils in question.

Curve Number (CN)

In most cases the curve numbers span a range having far less impact on the system than either R or Ks. If the user is working with a wide range of values for R and/or Ks there will be little need to calculate an exact CN. In this case, there is so much uncertainty in Ks that calculating an exact CN is not essential.

Were the user to have well defined R and Ks values, CN can be found by noting that, in this region, 'B' and 'C' type soils predominate (Table 3.1) and the predominant conservation practice is contour plowing. Soybeans, of course, is a row crop. Using a range of hydrologic soil conditions (poor to good) values of 75 to 84 can be selected from Table 3.6.

Step 3: Find the corresponding frequency distributions.

Use the address matrices at the beginning of Appendix A. For representative site #15 the matrix looks as follows:

Site #15
Crop: soybeans
CN: 71-85

	Ks				
R	.001	.005	.010	.050	.100
1	A15-1	A15-2	A15-3	A15-4	A15-5
3	A15-6	A15-7	A15-8	A15-9	A15-10
5	A15-11	A15-12	A15-13	A15-14	
20	A15-15	A15-16	A15-17		
50	A15-18	A15-19	A15-20		

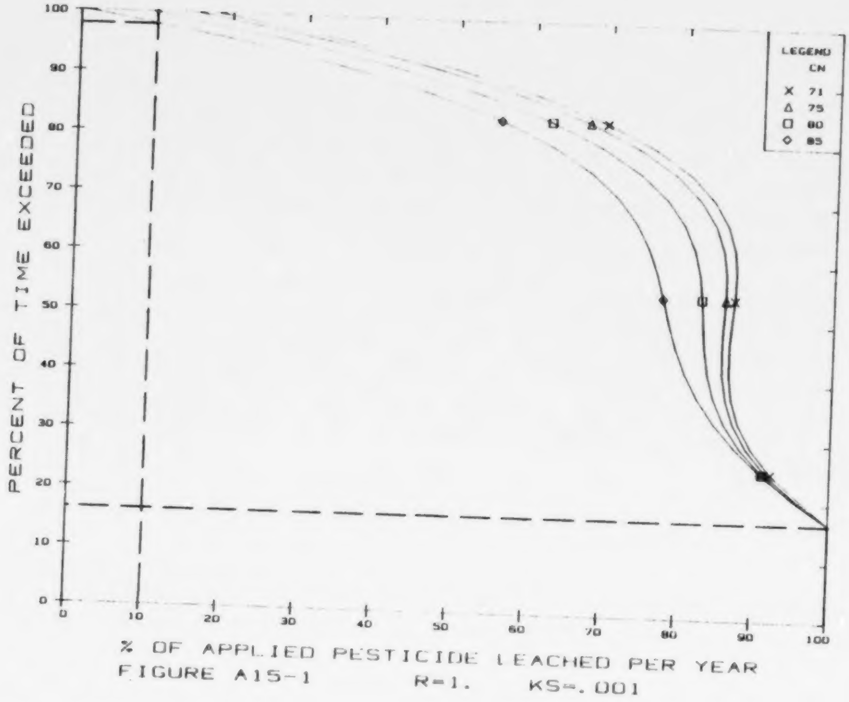
The calculations above have provided values of

R = 1 - 3
Ks = 0.0-.075
CN = 75-84

The relevant frequency distributions can be found in Figures A15-1 through A15-10.

Step 4: Interpret the frequency curves.

The worst case scenario is exemplified by plot A15-1, the other end of the spectrum by A15-10. Both plots are shown in Figure 5.1.



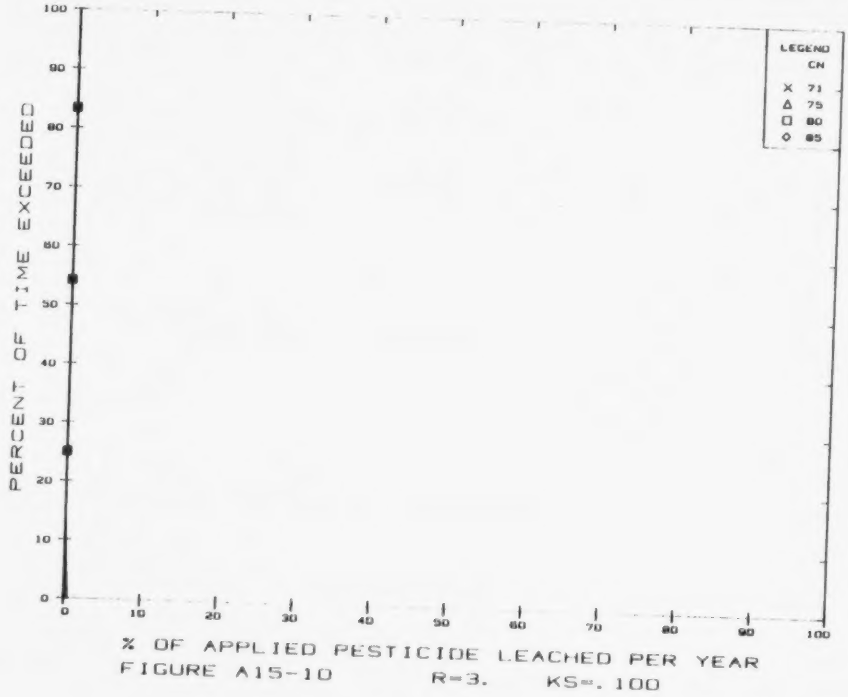


Figure 5.1 Frequency Curves for Example #1

For the worst case under all management scenarios (CN=71-85) some leaching can be expected. More specifically, for CN=85 there is a 98% chance that greater than 10% of the applied pesticide will be leached when the decay rate is very low. Regardless of management practice, there is an 18% chance that all of the applied pesticide will be leached. The reason that plot A15-1 shows that more than 100% of the applied pesticide could leach beyond the root zone is due to carry-over. The soil profile may retain pesticide in some years due to low precipitation and low pesticide decay rate. In relatively wet years all of the pesticide applied plus stored pesticide may migrate through.

Plot A15-10 (Figure 5.1) shows that under the best conditions very little pesticide is expected to leach.

The plots shown in Figure 5.1 reveal a large difference in outcome due to the range of expected decay rates. If a more precise indication of leaching potential is required, the range of Ks values used to address the plots must be reduced. The relative shapes and positions of the curves shown in Figure 5.1 indicate that more precise decay rate estimates can provide a more accurate assessment. If, on the other hand, the two plots had looked very similar, finding more detailed information about decay rates would not gain the user any more useful information. By looking at the orientation of curves at both extremes, indicated by the range of input parameters used, the user can identify which input parameters warrant further refinement.

5.2 EXAMPLE #2

The second example provides a case study of a site that lies just outside the boundaries of three representative sites, a few miles northeast of Rapid City, S.D. The pesticide chosen for this example is diuron, which is currently used on spring wheat in Oregon, Washington, and Idaho. This example was chosen to present an application in which complications arise due to insufficient or conflicting data.

Step 1: Choose site: Rapid City, S.D. long. 44 10'
lat. 103 05'
crop : Spring Wheat
pesticide : diuron

WSSA (1983) indicates that diuron is a pre- or postemergence herbicide which makes the analysis directly applicable.

Step 2: Calculate input parameters for locating frequency curves (R, Ks, CN)

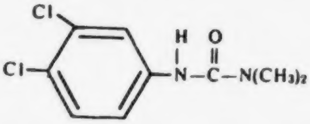
Retardation factor (R)

a) Look up Koc, Kow, or S value for diuron: Tables B-1 and B-3 give:

Kd = 8.9 CV = 150.8%
Koc = 382.6 CV = 72.4%
Kow = 650

In this case a range of Koc values is reported. Other references should be consulted to compare reported values. If, in this case, only a Kow value could be obtained, the following procedure would be followed:

The structural formula for diuron can be described as aromatic



with two chlorinated positions. According to Table 3.2 the best conversion equation from Kow to Koc for a chemical of this nature is equation 6. Substitution of the Kow value reported above into the equation yields

$$\log Koc = 1.00 (\log 650) - 0.21$$
$$Koc = 401$$

This value lies within the range of values for Koc by Rao and Davidson (1980). Unfortunately, Kow was reported as a single value with no associated range. Because this parameter is most influential in determining the potential for a compound to leach, more investigation is appropriate. The wide range of Koc values recorded in Appendix B for each pesticide indicates a large amount of uncertainty in its determination. For this example the range reported by Rao and Davidson will be used:

Koc = 382.6 %CV = 72.4 range = 106 - 660

Note: A value for Kd was also supplied by Rao and Davidson. Kd values may be used in the calculation of R, but they introduce an element of uncertainty beyond reported values of Koc and Kow. Kd is determined according to the amount of OC present in the soil and thus is a function of both the chemical and soil properties combined. Unless the user is aware of the soil used in its determination, reported Kd values may be misleading. In this case the range of Kd values reported is 0. to 13.4. The range of Kd values calculated from the reported values of Koc and OC for this site is .6 to 19.8. In this case the values are similar, but if the OC content had been higher, the reported range of Kd would have been too low.

b) Determine organic carbon (OC) in soil from reported values or calculation. Figure 3.6 indicates that this site lies in an area having a range of soil nitrogen values from 0.10 to 0.19%. Thus the % organic carbon ranges from 1.1 to 2.1.

c) Determine bulk density (ρs) from the soil texture classification. This example site lies just outside of three representative sites (nos. 3, 4, and 5). In this case the Mead Co., South Dakota soil survey reports primarily loams and silt loams present. The range of ρs values covering these two textural classifications is 0.86 to 1.67. Note in addition that sites 3, 4, and 5 are characterized by predominantly loam, and sandy loam soils, respectively, which have a ρs range of 1.16 to 1.76. Therefore, little uncertainty is introduced into the bulk density parameter by using site 3, 4, or 5 as representative.

d) Determine field capacity (θfc) from soil textural classification. Like bulk density, field capacity values span a relatively small range. Field capacity can also be determined from soil textural information. Using the same technique as for bulk density determination, θfc for loams and silt loams covers the range from 0.195 to 0.402 (Table 3.4). Figure 3.8 could also have been used. Using the range of reported ρs, the range of θfc is predicted as 0.12 to 0.65. The narrower range from Table 3.4 will be used here.

e) Calculate R: (equation 3.1)

$$R_{low} = 1 + \frac{106\ (0.011)\ (0.86)}{0.402} = 3.5$$

$$R_{high} = 1 + \frac{660\ (0.021)\ (1.67)}{0.195} = 120$$

This range of values for R is quite large. The cases presented in this handbook cover the range 1 to 50. For this case there is a fair amount of uncertainty in all of the components of R. This results in a situation where a clear-cut decision cannot be made about the leaching potential of diuron in this application.

This will be discussed further following the determination of Ks and CN.

Decay Rate (Ks)

Values for Ks must be found in the chemical literature. Some values are reported in Appendix B. From Tables B-5 and B-6,

Ks for diuron = 0.136 and 0.214 (soil surface) and
0.0064 and 0.0072 (soil)

Since these values are so disparate alternative information should be sought to narrow the range. Rao and Davidson (1980) report values of Ks for diuron at 0.0031 with a coefficient of variation of 58.1%. This gives a one standard deviation range of 0.0013 to 0.0049. The upper end of this range has values similar to those reported in Appendix B. This range will be used in this example. For the present the very high values in Table B-5 will be ignored.

Curve Number (CN)

In most cases the curve numbers span a range having far less impact on the system than either R or Ks. Again, when the user is working with a wide range of values for R and/or Ks there will be little need to calculate an exact CN. We will assume in this example that the curve numbers for wheat in the area cover the entire range found in the address matrix.

In this case the calculated value for R does cover a wide range of possibilities. Because the range of values extends into those indicating a potential leaching hazard, further investigation is warranted. This will require the user to obtain more accurate values for the component variables in R, especially Koc. The range of values reported by Rao and Davidson for Koc were determined on 84 soils. Although this is a large sample size, a more detailed look at the 84 values and soil types is in order. A few values could be causing the wide spread. By narrowing this range a more accurate estimate of a potential leaching hazard is possible. In another circumstance, a wide range of R values may not require further refinement. If the entire range had fallen outside those values used for this handbook development (e.g., R = 100 to 500), no significant leaching would be predicted for the 25 year period.

Step 3: Find the corresponding frequency curve(s):

This test site lies outside, but close to, the boundaries of three representative sites. Although bulk densities are roughly equivalent between the Meade Co., South Dakota soils and the site 3, 4, or 5 representative soils, the indication is that the loams and silt loams (Meade Co.) have higher values of field capacity than the loams of site 5 (Table 3.4). Therefore site 5 can probably be eliminated. Higher field capacities would give lower values of R and therefore site 3 or 4 frequency curves would slightly overpredict leaching, all other factors being constant. Figure 4.11, however, shows that precipitation in Rapid City is in the neighborhood of 15 to 20 inches (38 to 51 cm). Table 4.2 reveals that the meteorological stations used for sites 3 and 4 had annual normal totals of 11.6 and 15.6 inches (29 and 40 cm) respectively. Thus site 3 would be eliminated in preference to site 4 based on rainfall considerations. The appropriate curves are determined by looking at the address matrix for representative site 4. The address matrix is shown below:

Site #4
Crop: Wheat
CN: 70-84

		Ks				
		.001	.005	.010	.050	.100
R	1	A4-1	A4-2	A4-3	A4-4	A4-5
	3	A4-6	A4-7	A4-8	A4-9	A4-10
	5	A4-11	A4-12	A4-13	A4-14	
	20	A4-15				
	50	A4-16				

Figure A4-1, represents the worst case at site #4. Using the full range of values calculated for R and Ks Figures A4-1, A4-2, A4-6, A4-7, A4-11, A4-12, A4-15 and A4-16 are all pertinent.

Step 4: Interpret the curves

Inspection of Figure A4-1 (Appendix A) reveals that leaching of diuron is potentially quite high. Under worst case (CN = 70) there is a 100% chance that at least 48% of the compound will leach below the crop rooting depth. Increasing the decay rate from 0.001/day to 0.005/day results in a decrease of about one-third in amount leached (Figure A4-2). One can see that as R and Ks get incrementally larger, that the amount leached decreases drastically (Figure A4-2, A4-6, A4-7, A4-11, A4-12, A4-15). Under the best circumstances shown (Figure A4-16), there is no case in which more than 10 or 12% of the annually applied quantity is leached. It is obvious that to get a more definative answer in this circumstance that uncertainty in the value of Kd must be reduced.

Finally, application rates of diuron vary from 0.7 to 18 Kg/ha for most agricultural applications (WSSA, 1983). Ag Consultants, (1983) indicate rates from 0.9 to 1.35 Kg/ha in spring wheat. Multiplication of the percentages from Figures A4-1, etc. by a typical application rate would give the actual load of the pesticide below the crop root zone.

SECTION 6

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APPENDIX A

SITE NO. 1
CROP: WHEAT
CN: 78-84

		Ks				
		.001	.005	.010	.050	.100
	1	A1-1	A1-2	A1-3	A1-4	A1-5
	3	A1-6	A1-7	A1-8	A1-9	
R	5	A1-10	A1-11	A1-12	A1-13	
	20	A1-14	A1-15			
	50	A1-16				

SITE NO. 2
CROP: WHEAT
CN: 70-84

		Ks				
		.001	.005	.010	.050	.100
	1	A2-1	A2-2	A2-3	A2-4	A2-5
	3	A2-6	A2-7	A2-8	A2-9	
R	5	A2-10	A2-11	A2-12		
	20	A2-13				
	50					

SITE NO. 3
CROP: WHEAT
CN: 59-84

		Ks				
		.001	.005	.010	.050	.100
	1	A3-1	A3-2	A3-3	A3-4	A3-5
	3	A3-6	A3-7	A3-8	A3-9	A3-10
R	5	A3-11	A3-12	A3-13	A3-14	
	20	A3-15				
	50					

SITE NO. 4
CROP: WHEAT
CN: 70-84

		Ks				
		.001	.005	.010	.050	.100
	1	A4-1	A4-2	A4-3	A4-4	A4-5
	3	A4-6	A4-7	A4-8	A4-9	A4-10
R	5	A4-11	A4-12	A4-13	A4-14	
	20	A4-15				
	50	A4-16				

SITE NO. 5
CROP: WHEAT
CN: 59-84

		Ks				
		.001	.005	.010	.050	.100
	1	A5-1	A5-2	A5-3	A5-4	A5-5
	3	A5-6	A5-7	A5-8	A5-9	A5-10
R	5	A5-11	A5-12	A5-13	A5-14	
	20	A5-15	A5-16			
	50	A5-17				

SITE NO. 6
CROP: WHEAT
CN: 59-65

		Ks				
		.001	.005	.010	.050	.100
	1	A6-1	A6-2	A6-3	A6-4	A6-5
	3	A6-6	A6-7	A6-8	A6-9	A6-10
R	5	A6-11	A6-12	A6-13	A6-14	A6-15
	20	A6-16	A6-17	A6-18		
	50	A6-19	A6-20			

SITE NO. 7
CROP: CORN
CN: 78-85

Ks

		.001	.005	.010	.050	.100
	1	A7-1	A7-2	A7-3	A7-4	A7-5
	3	A7-6	A7-7	A7-8	A7-9	A7-10
R	5	A7-11	A7-12	A7-13		
	20	A7-14	A7-15			
	50					

SITE NO. 8
CROP: CORN
CN: 71-91

Ks

		.001	.005	.010	.050	.100
	1	A8-1	A8-2	A8-3	A8-4	A8-5
	3	A8-6	A8-7	A8-8		
R	5	A8-9	A8-10			
	20	A8-11				
	50					

SITE NO. 9
CROP: CORN
CN: 78-85

Ks

R		.001	.005	.010	.050	.100
	1	A9-1	A9-2	A9-3	A9-4	A9-5
	3	A9-6	A9-7	A9-8	A9-9	
R	5	A9-10	A9-11	A9-12		
	20	A9-13	A9-14			
	50					

SITE NO. 10
CROP: CORN
CN: 71-78

Ks

R		.001	.005	.010	.050	.100
	1	A10-1	A10-2	A10-3	A10-4	A10-5
	3	A10-6	A10-7	A10-8	A10-9	
R	5	A10-10	A10-11	A10-12	A10-13	
	20	A10-14	A10-15			
	50	A10-16	A10-17			

SITE NO. 11
CROP: CORN
CN: 71-78

		Ks				
		.001	.005	.010	.050	.100
R	1	A11-1	A11-2	A11-3	A11-4	A11-5
	3	A11-6	A11-7	A11-8	A11-9	
	5	A11-10	A11-11	A11-12	A11-13	
	20	A11-14	A11-15			
	50	A11-16	A11-17			

SITE NO. 12
CROP: CORN
CN: 78-85

		Ks				
		.001	.005	.010	.050	.100
R	1	A12-1	A12-2	A12-3	A12-4	A12-5
	3	A12-6	A12-7	A12-8	A12-9	
	5	A12-10	A12-11	A12-12	A12-13	
	20	A12-14	A12-15			
	50	A12-16	A12-17			

SITE NO. 13
CROP: CORN
CN: 78-91

		Ks				
		.001	.005	.010	.050	.100
R	1	A13-1	A13-2	A13-3	A13-4	A13-5
	3	A13-6	A13-7	A13-8	A13-9	
	5	A13-10	A13-11	A13-12		
	20	A13-13	A13-14			
	50	A13-15				

SITE NO. 14
CROP: SOYBEANS
CN: 71-85

		Ks				
		.001	.005	.010	.050	.100
R	1	A14-1	A14-2	A14-3	A14-4	A14-5
	3	A14-6	A14-7	A14-8	A14-9	A14-10
	5	A14-11	A14-12	A14-13	A14-14	
	20	A14-15	A14-16			
	50	A14-17	A14-18			

SITE NO. 15
CROP: SOYBEANS
CN: 71-85

		Ks				
		.001	.005	.010	.050	.100
R	1	A15-1	A15-2	A15-3	A15-4	A15-5
	3	A15-6	A15-7	A15-8	A15-9	A15-10
	5	A15-11	A15-12	A15-13	A15-14	
	20	A15-15	A15-16	A15-17		
	50	A15-18	A15-19	A15-20		

SITE NO. 16
CROP: SOYBEANS
CN: 71-85

		Ks				
		.001	.005	.010	.050	.100
R	1	A16-1	A16-2	A16-3	A16-4	A16-5
	3	A16-6	A16-7	A16-8	A16-9	A16-10
	5	A16-11	A16-12	A16-13	A16-14	
	20	A16-15	A16-16	A16-17		
	50	A16-18	A16-19	A16-20		

SITE NO. 17
CROP: SOYBEANS
CN: 78-91

		Ks				
		.001	.005	.010	.050	.100
R	1	A17-1	A17-2	A17-3	A17-4	A17-5
	3	A17-6	A17-7	A17-8	A17-9	A17-10
	5	A17-11	A17-12	A17-13	A17-14	
	20	A17-15	A17-16	A17-17		
	50	A17-18	A17-19			

SITE NO. 18
CROP: COTTON
CN: 71-91

		Ks				
		.001	.005	.010	.050	.100
R	1	A18-1	A18-2	A18-3	A18-4	A18-5
	3	A18-6	A18-7	A18-8	A18-9	
	5	A18-10	A18-11	A18-12		
	20	A18-13	A18-14			
	50	A18-15				

SITE NO. 19
CROP: COTTON
CN: 71-85

		Ks				
		.001	.005	.010	.050	.100
R	1	A19-1	A19-2	A19-3	A19-4	A19-5
	3	A19-6	A19-7	A19-8	A19-9	A19-10
	5	A19-11	A19-12	A19-13	A19-14	
	20	A19-15	A19-16			
	50	A19-17	A19-18			

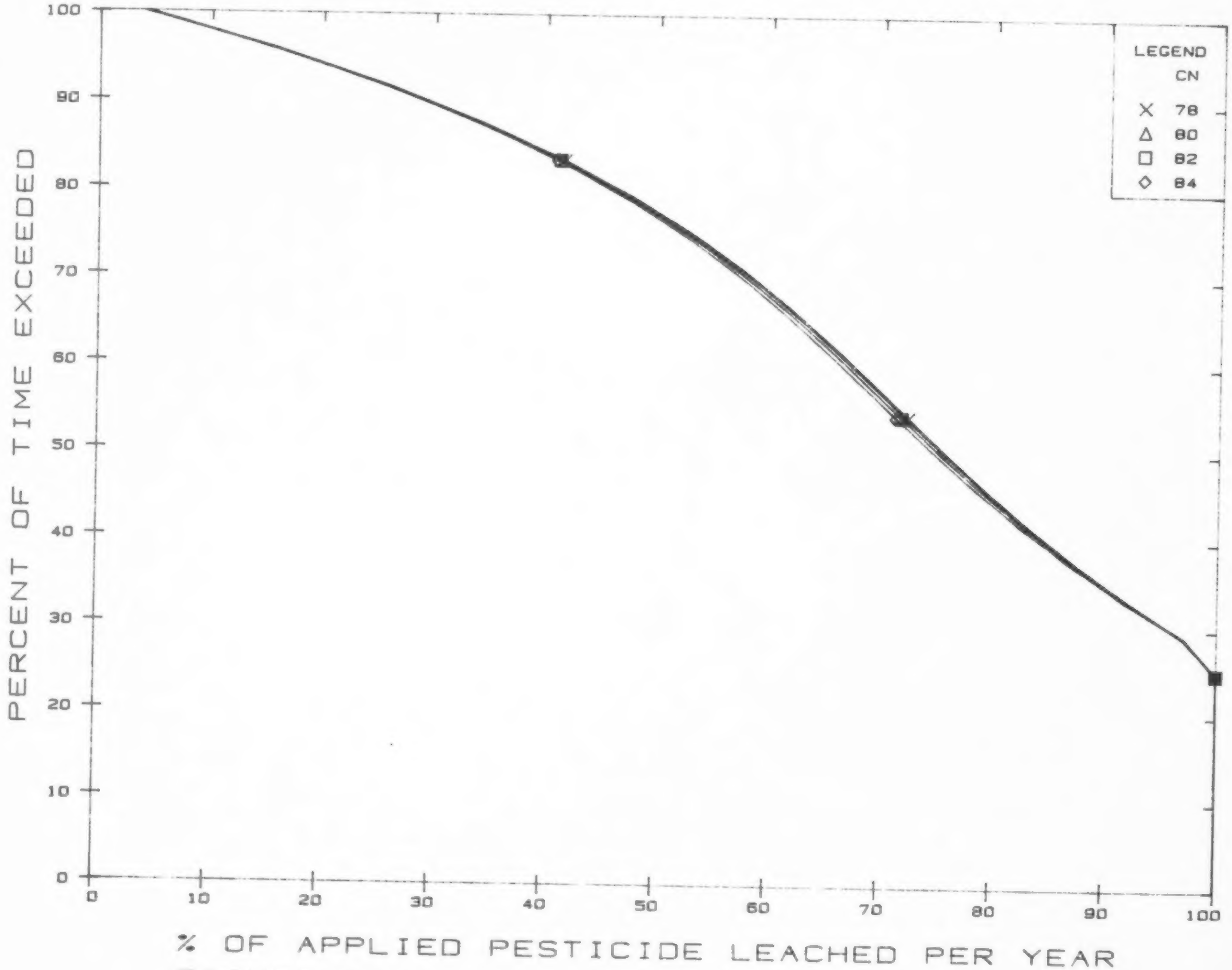


FIGURE A1-1 R=1. KS=.001

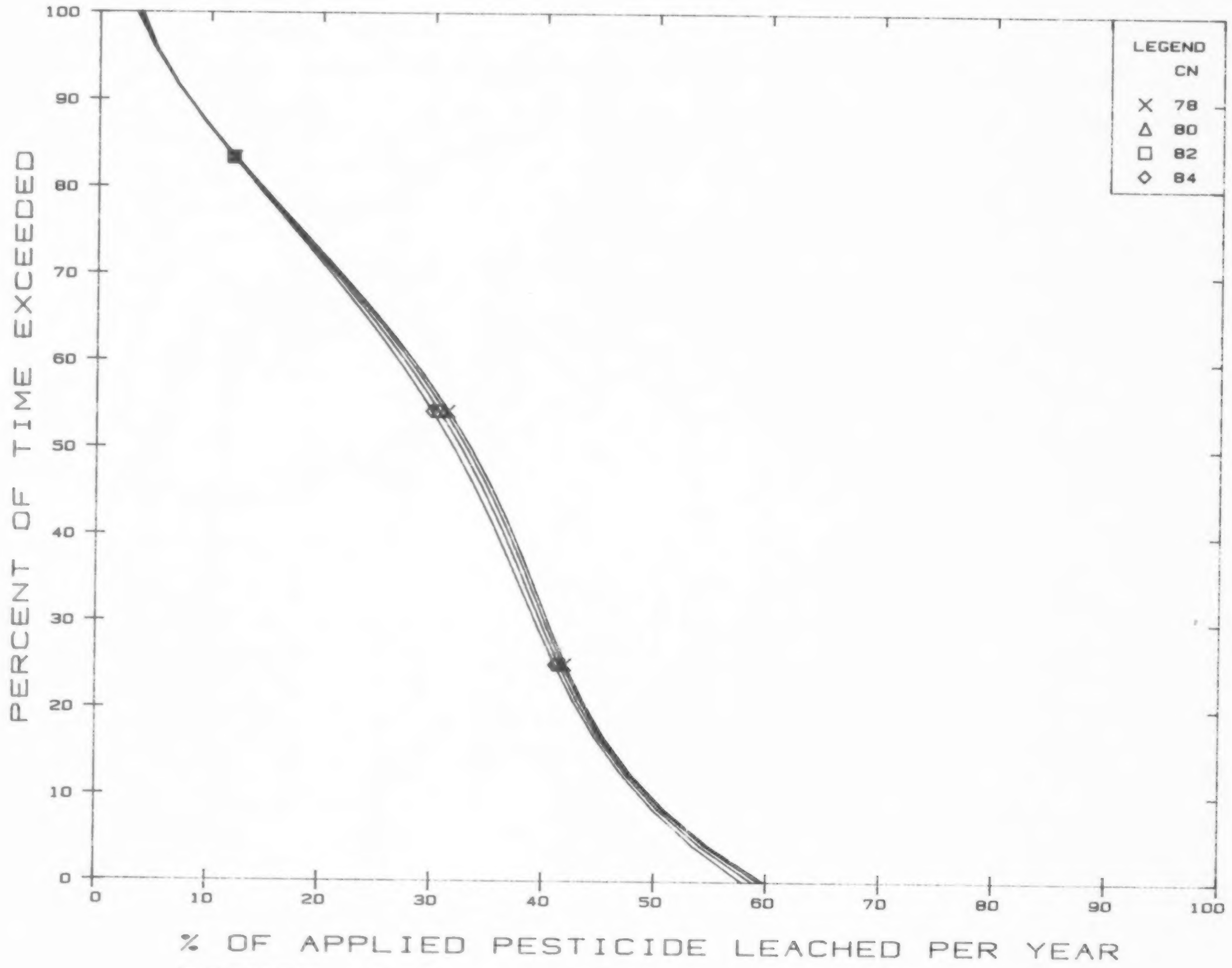


FIGURE A1-2 R=1. KS=.005

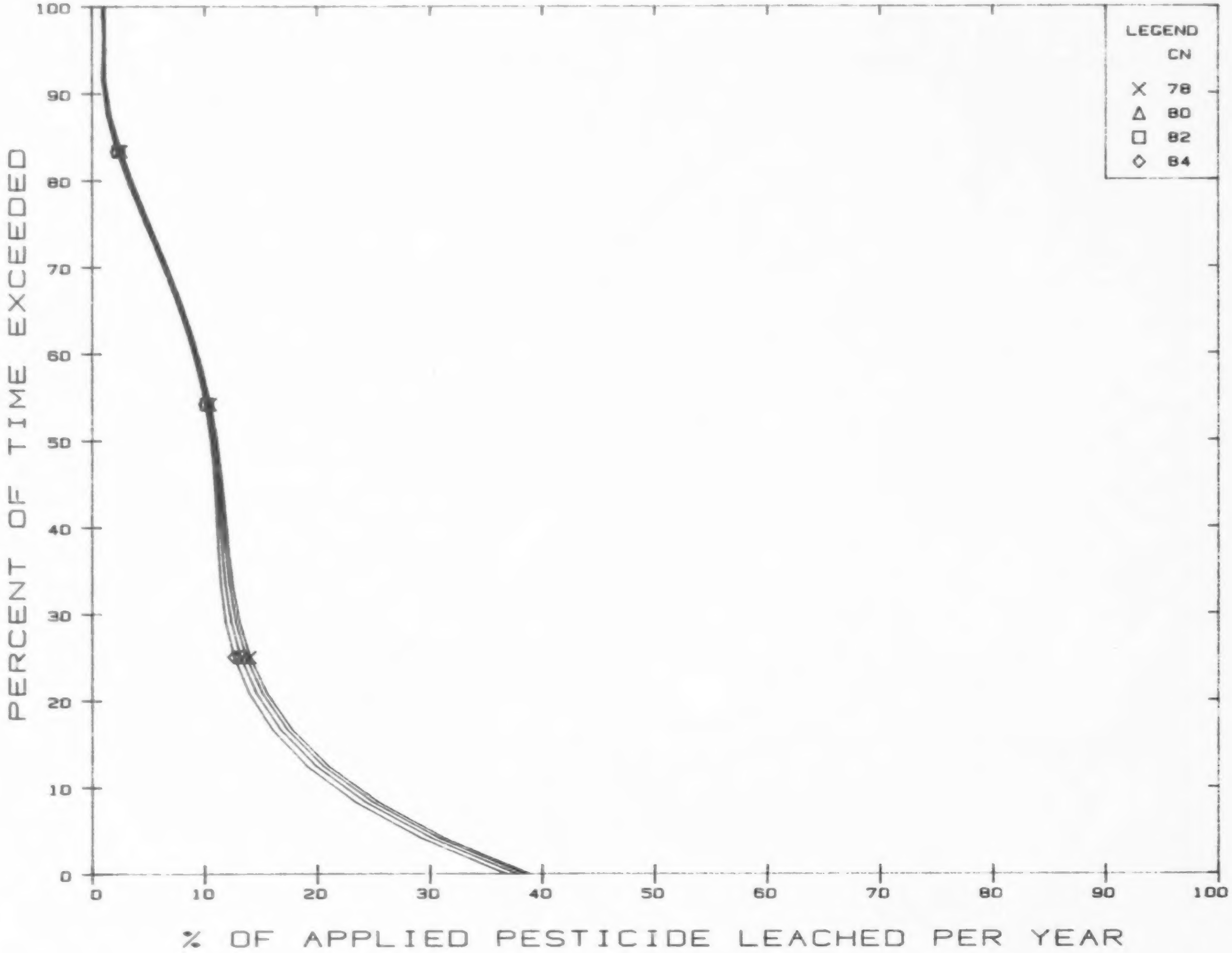


FIGURE A1-3 R=1. KS=.010

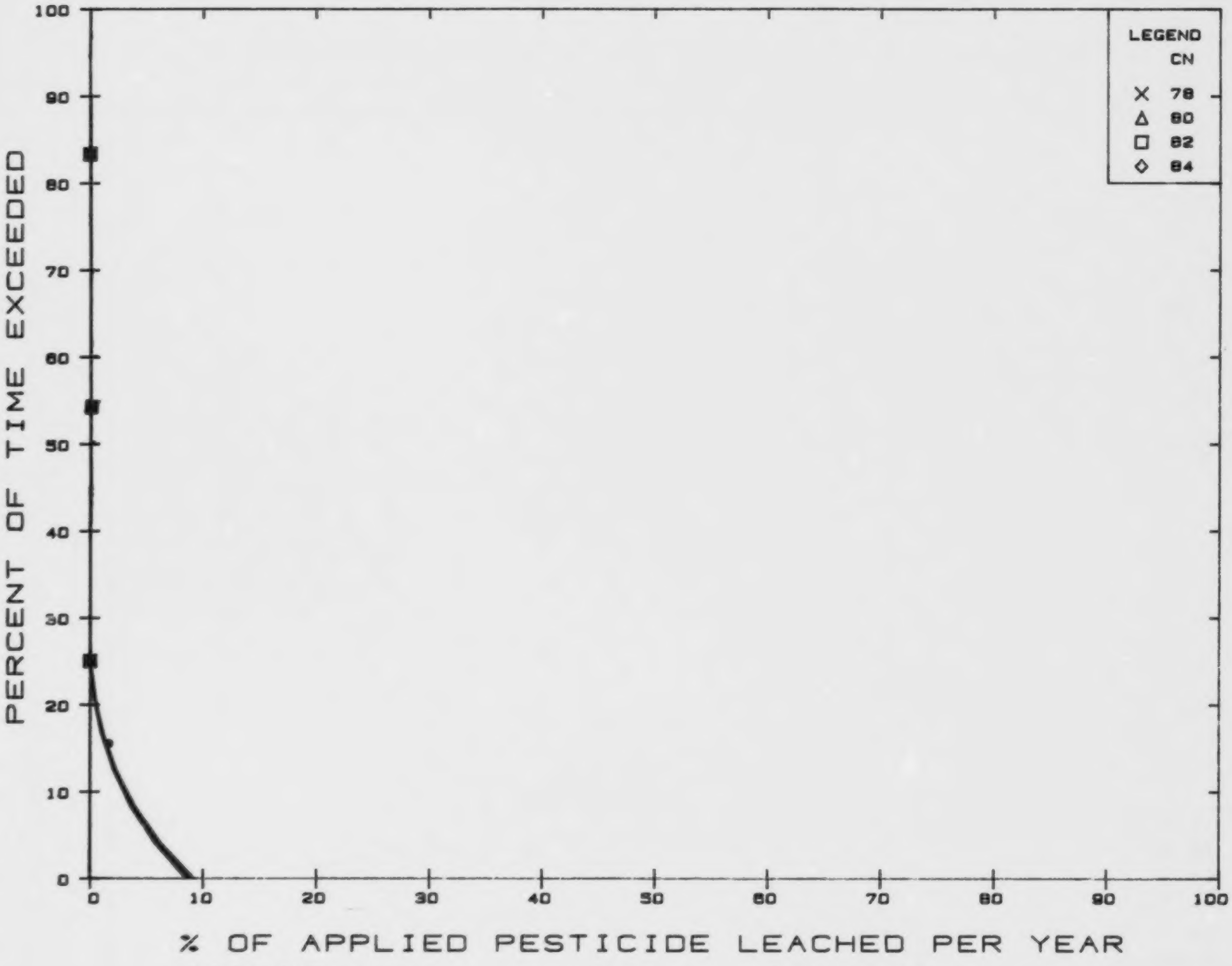


FIGURE A1-4 R=1. KS=.050

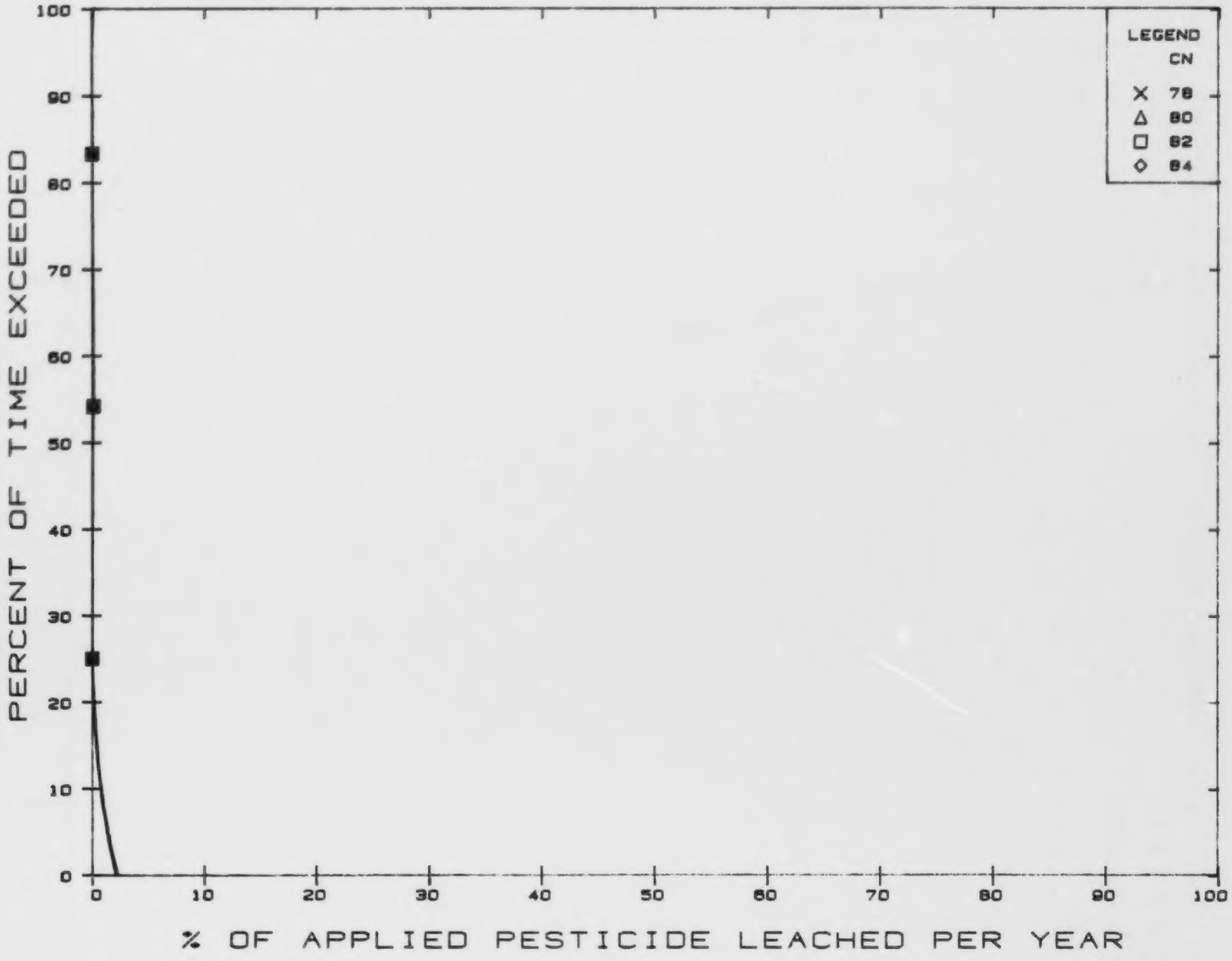


FIGURE A1-5 R=1. KS=.100

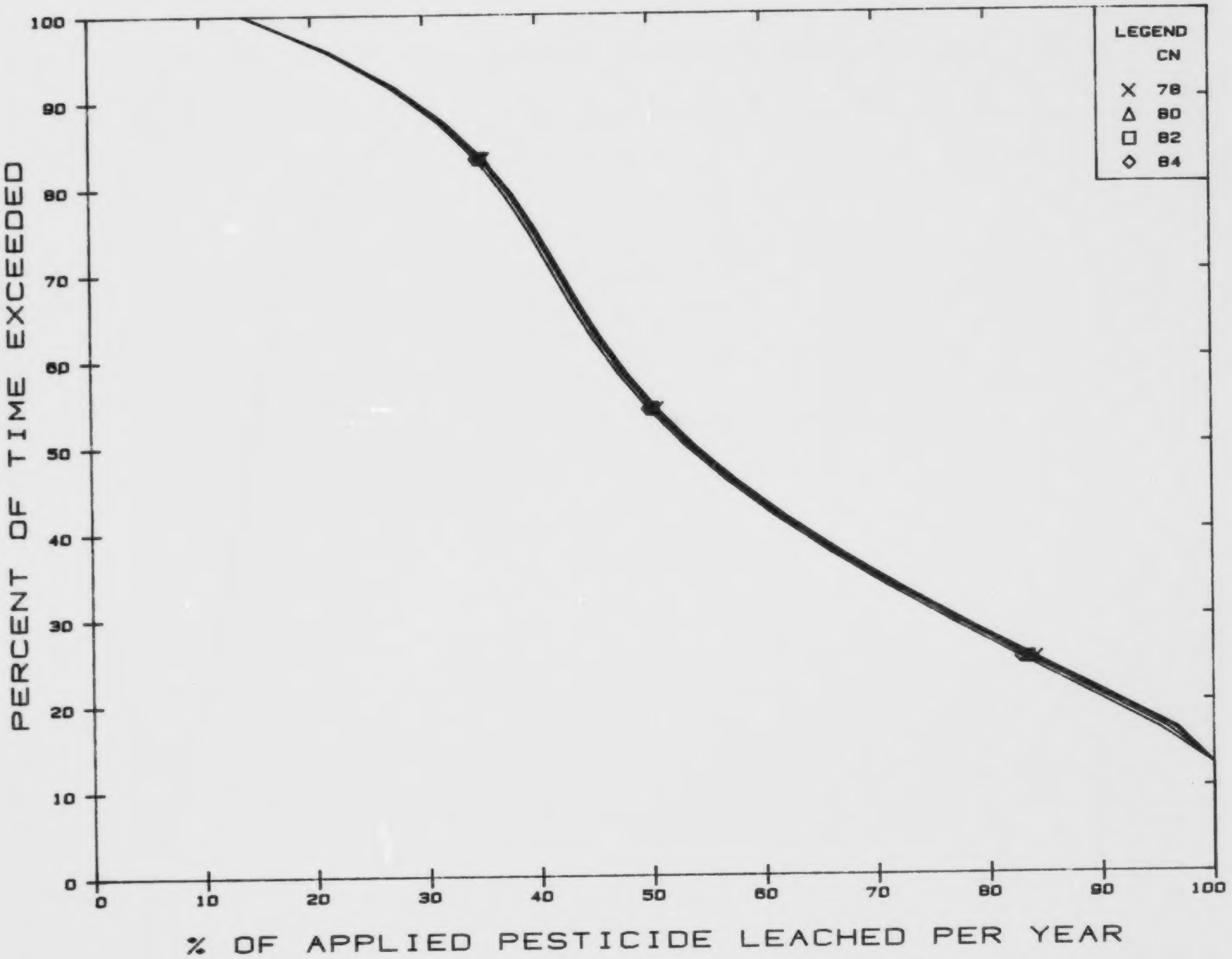


FIGURE A1-6 R=3. KS=.001

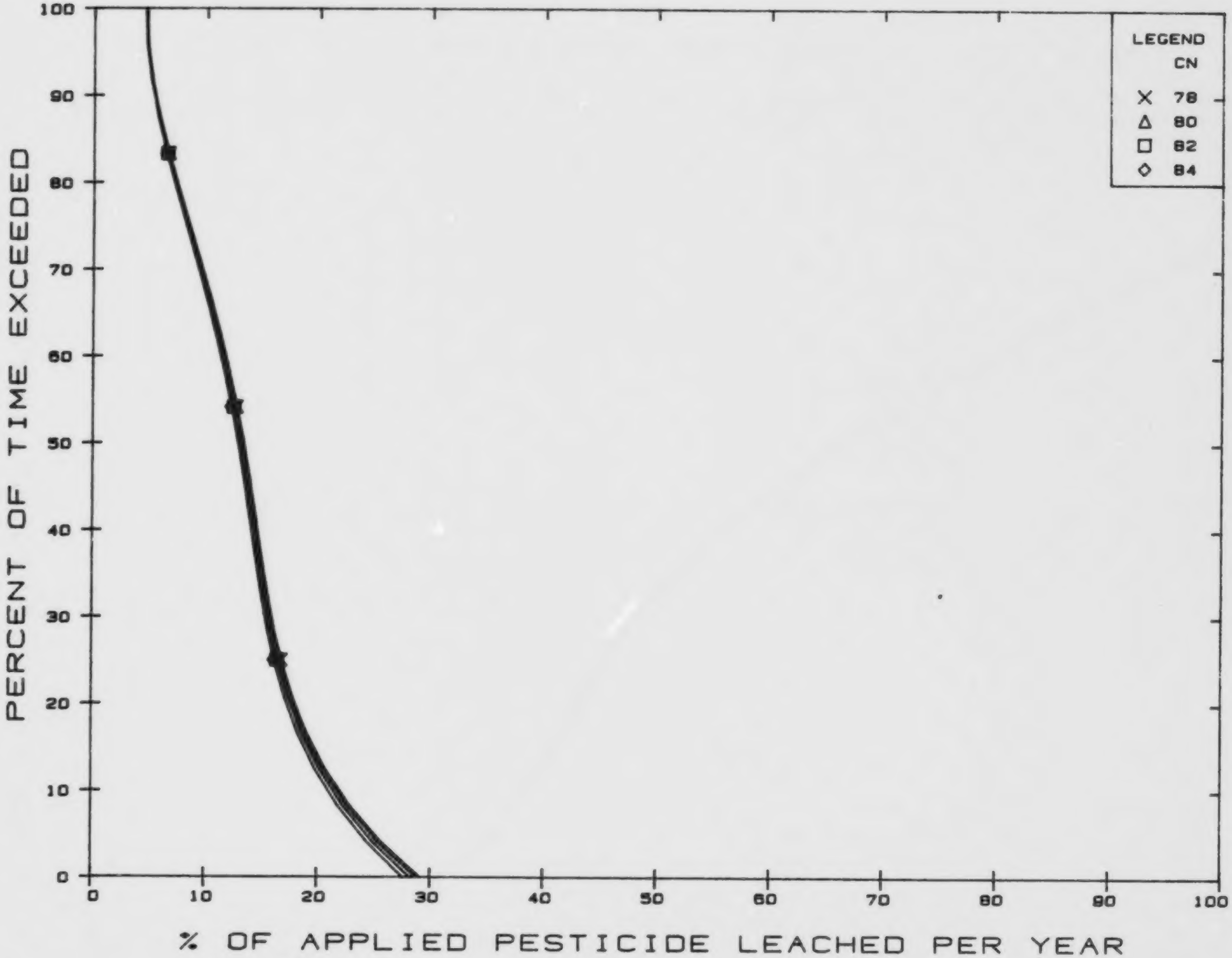


FIGURE A1-7 R=3. KS=.005

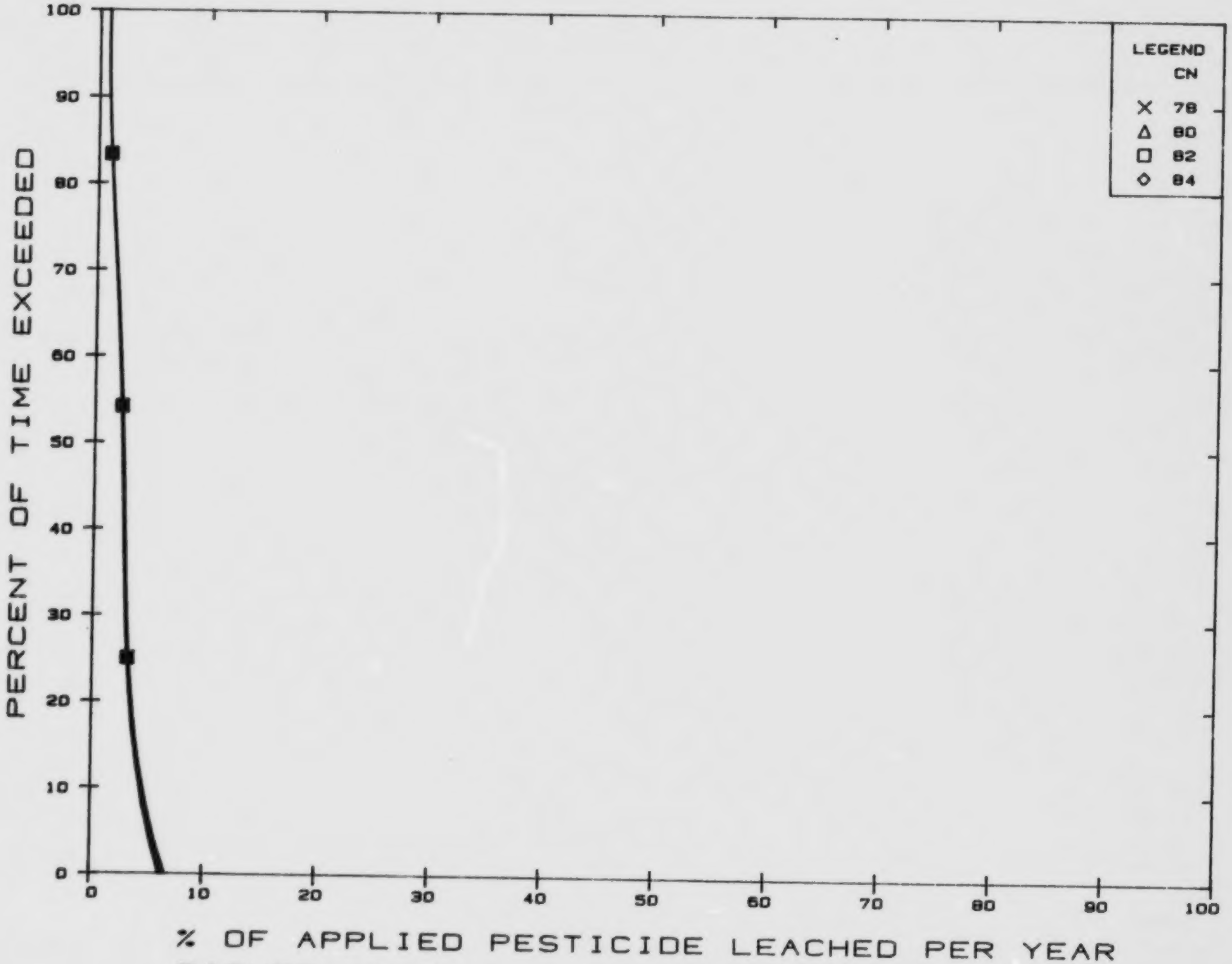


FIGURE A1-8 R=3. KS=.010

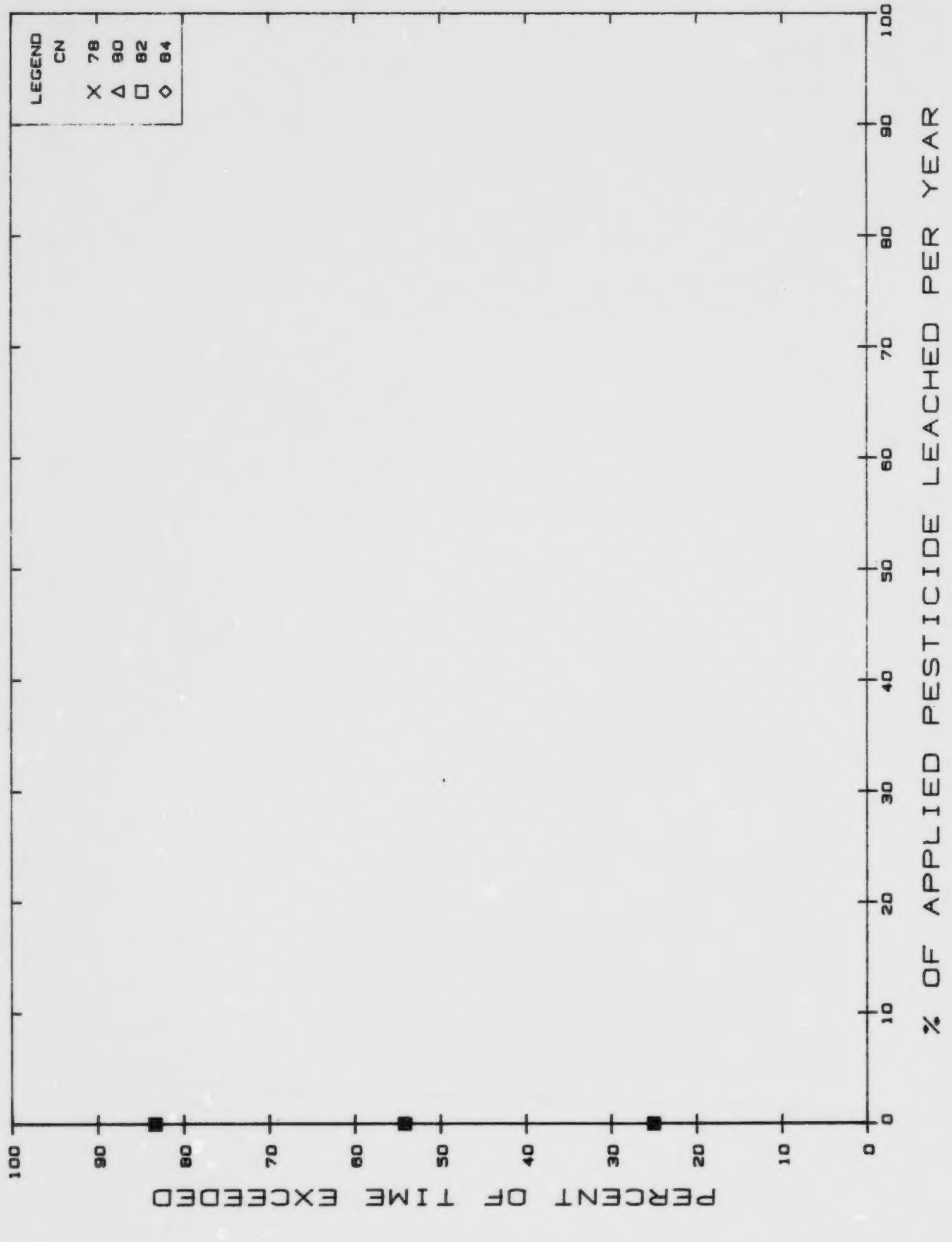
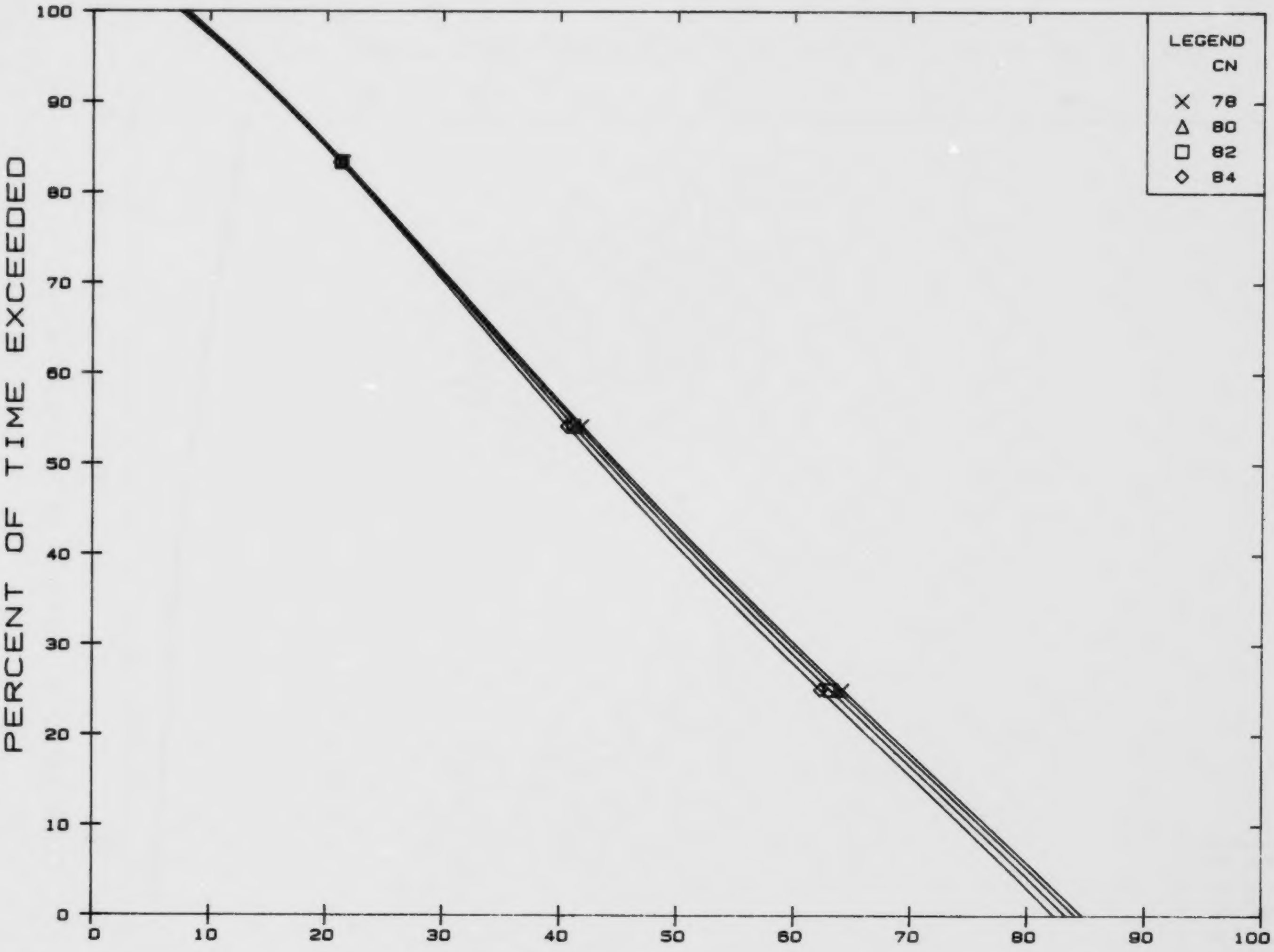


FIGURE A1-9 R=3. KS=.050



% OF APPLIED PESTICIDE LEACHED PER YEAR
FIGURE A1-10 R=5. KS=.001

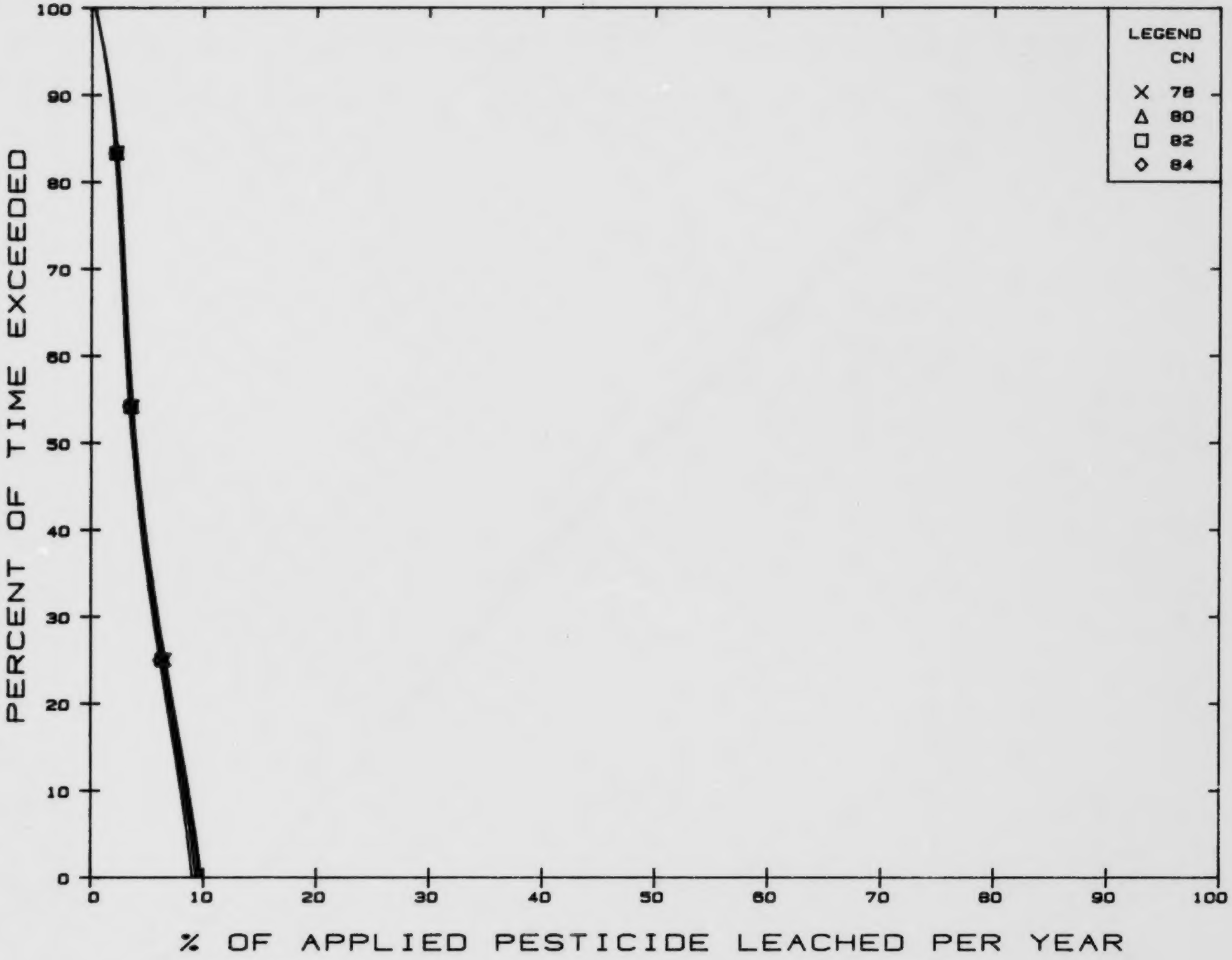


FIGURE A1-11 R=5. KS=.005

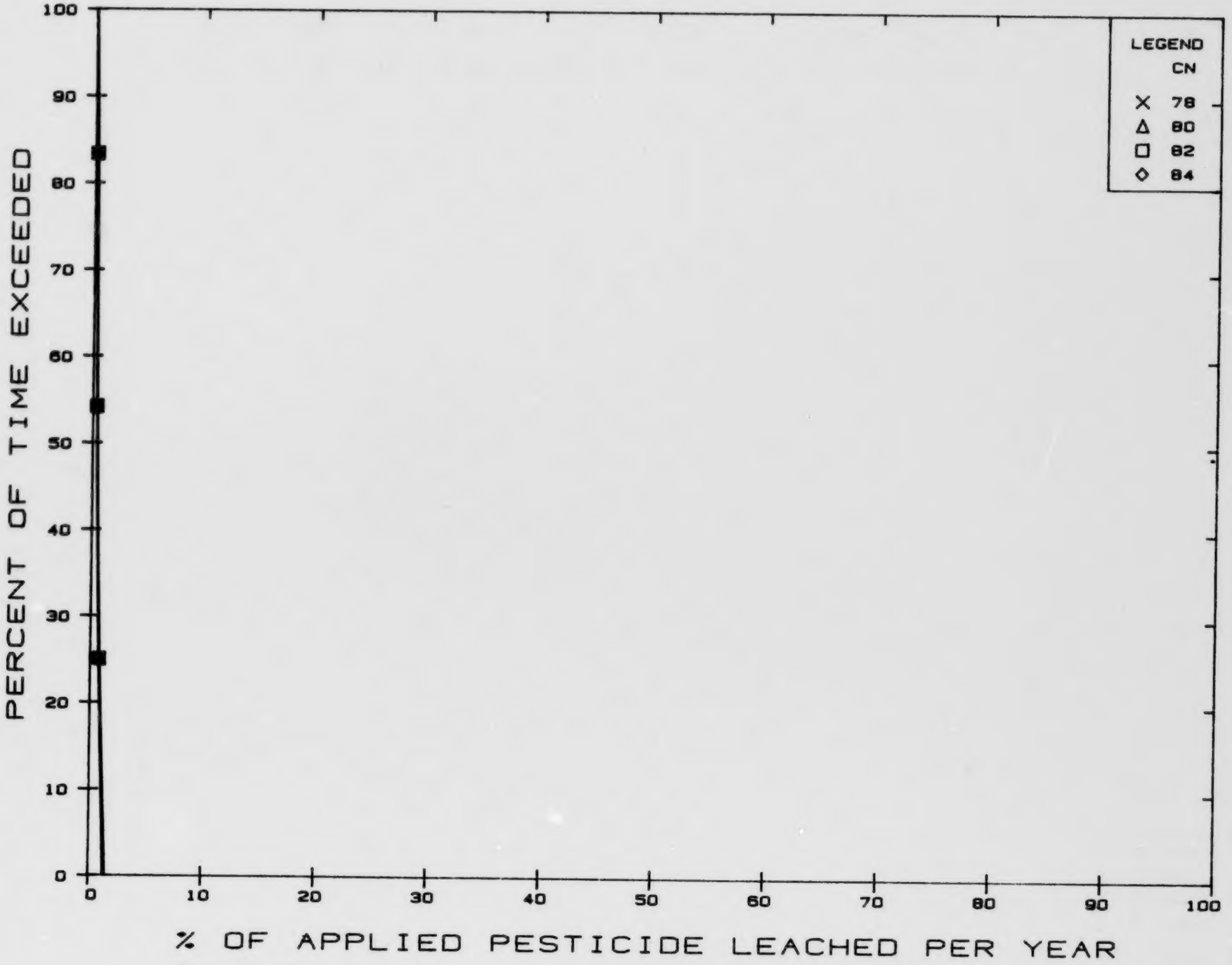


FIGURE A1-12 R=5. KS=.010

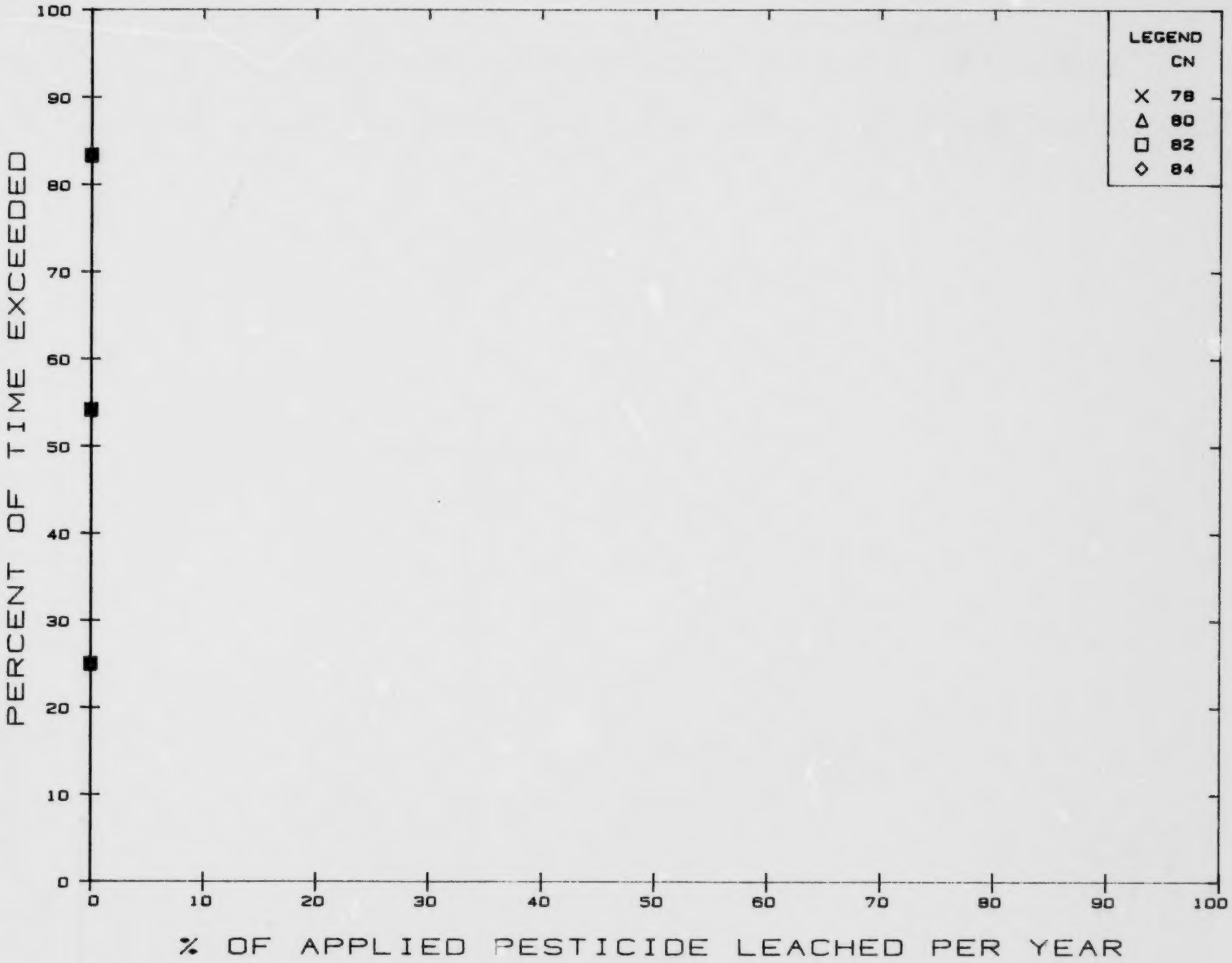


FIGURE A1-13 R=5. KS=.050

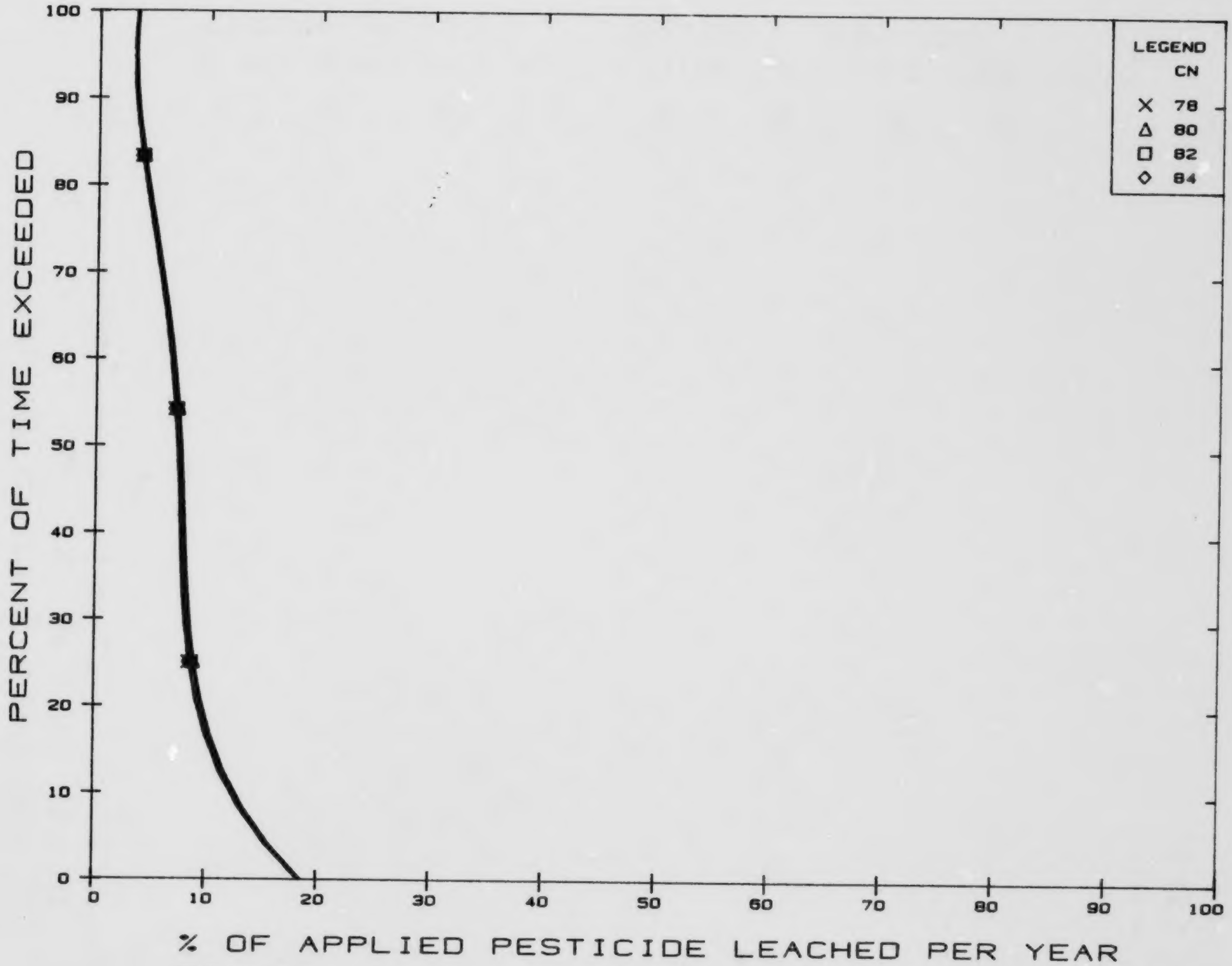
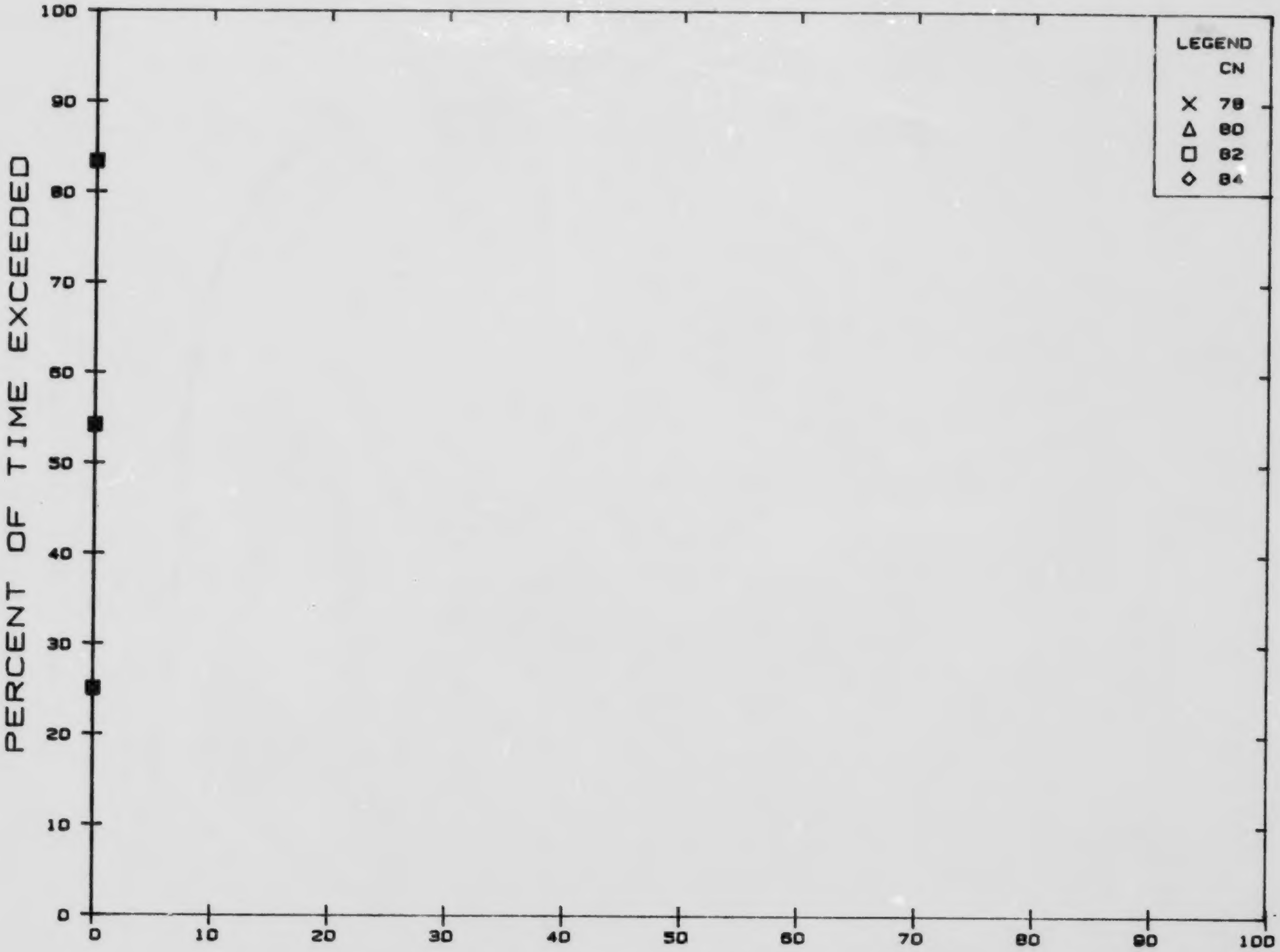


FIGURE A1-14 R=20. KS=.001



% OF APPLIED PESTICIDE LEACHED PER YEAR

FIGURE A1-15 R=20. KS=.005

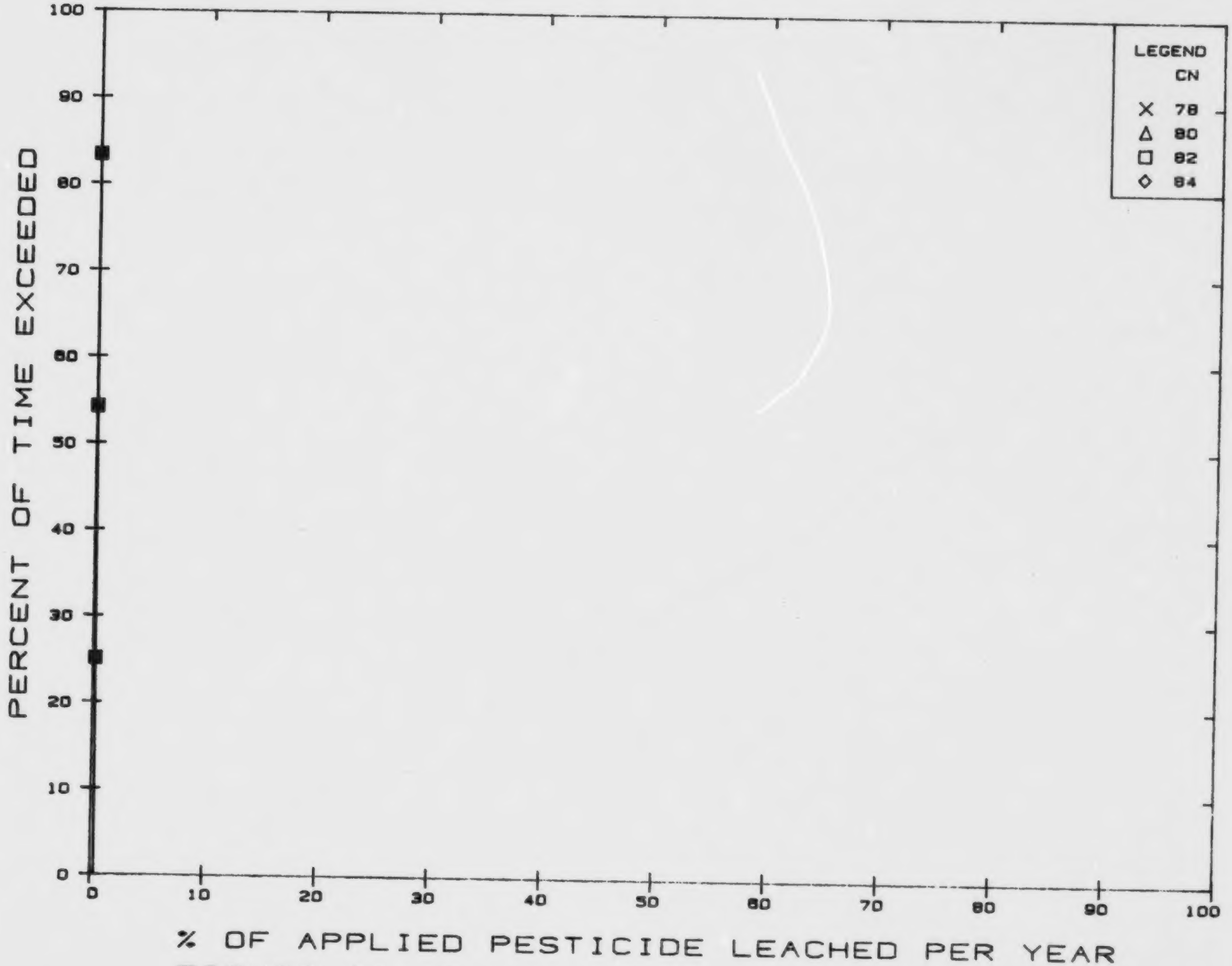


FIGURE A1-16 R=50. KS=.001

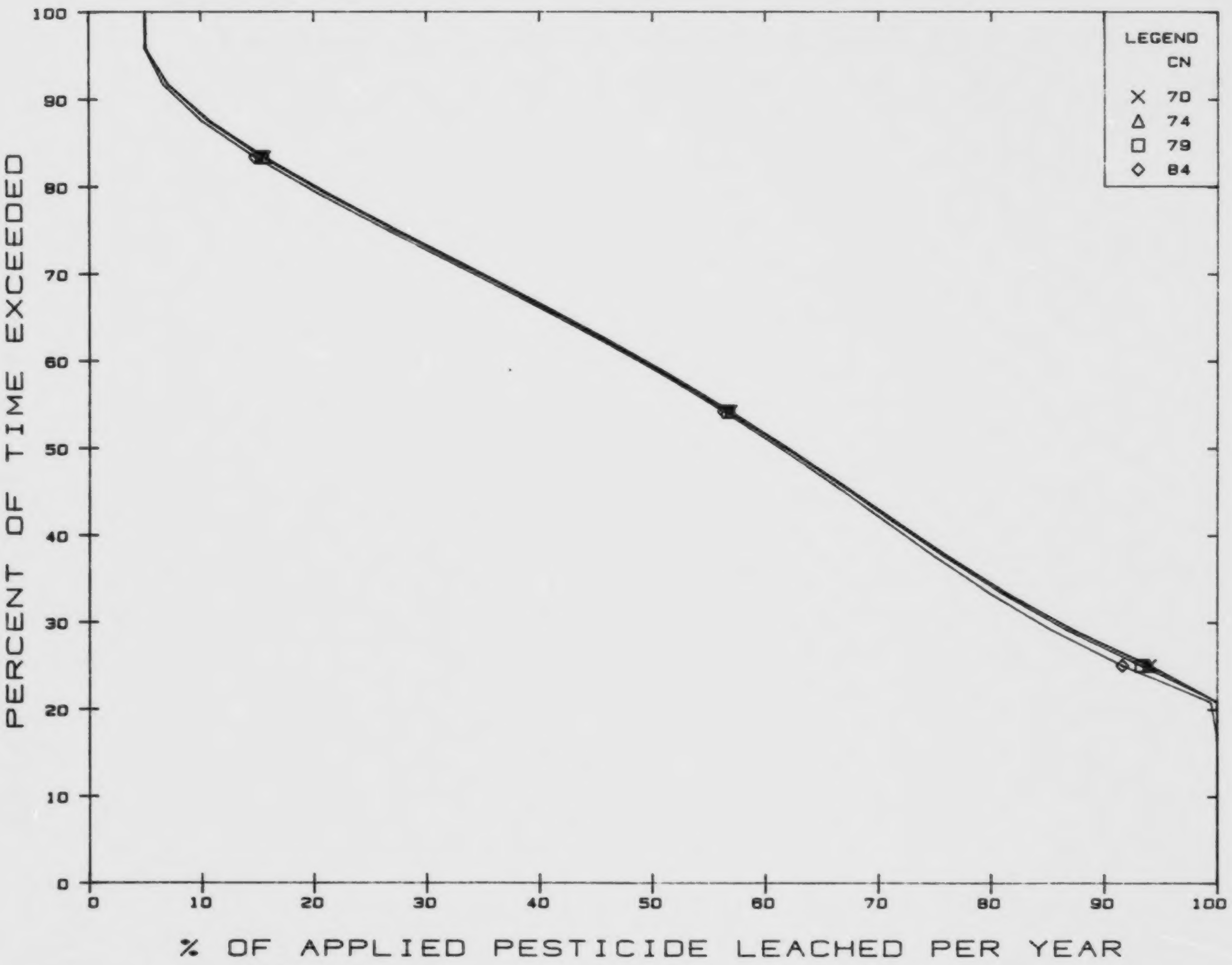


FIGURE A2-1 R=1. KS=.001

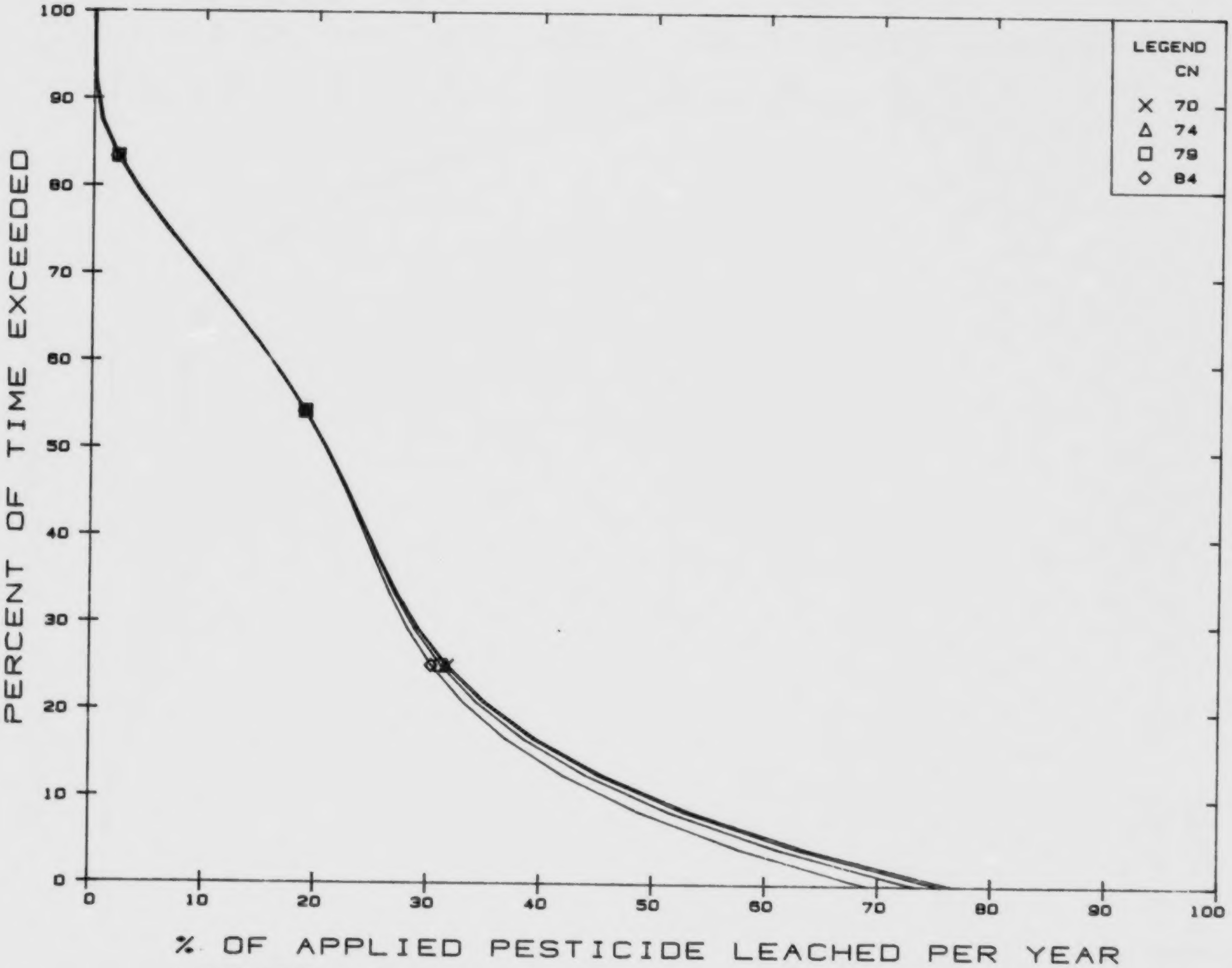


FIGURE A2-2 R=1. KS=.005

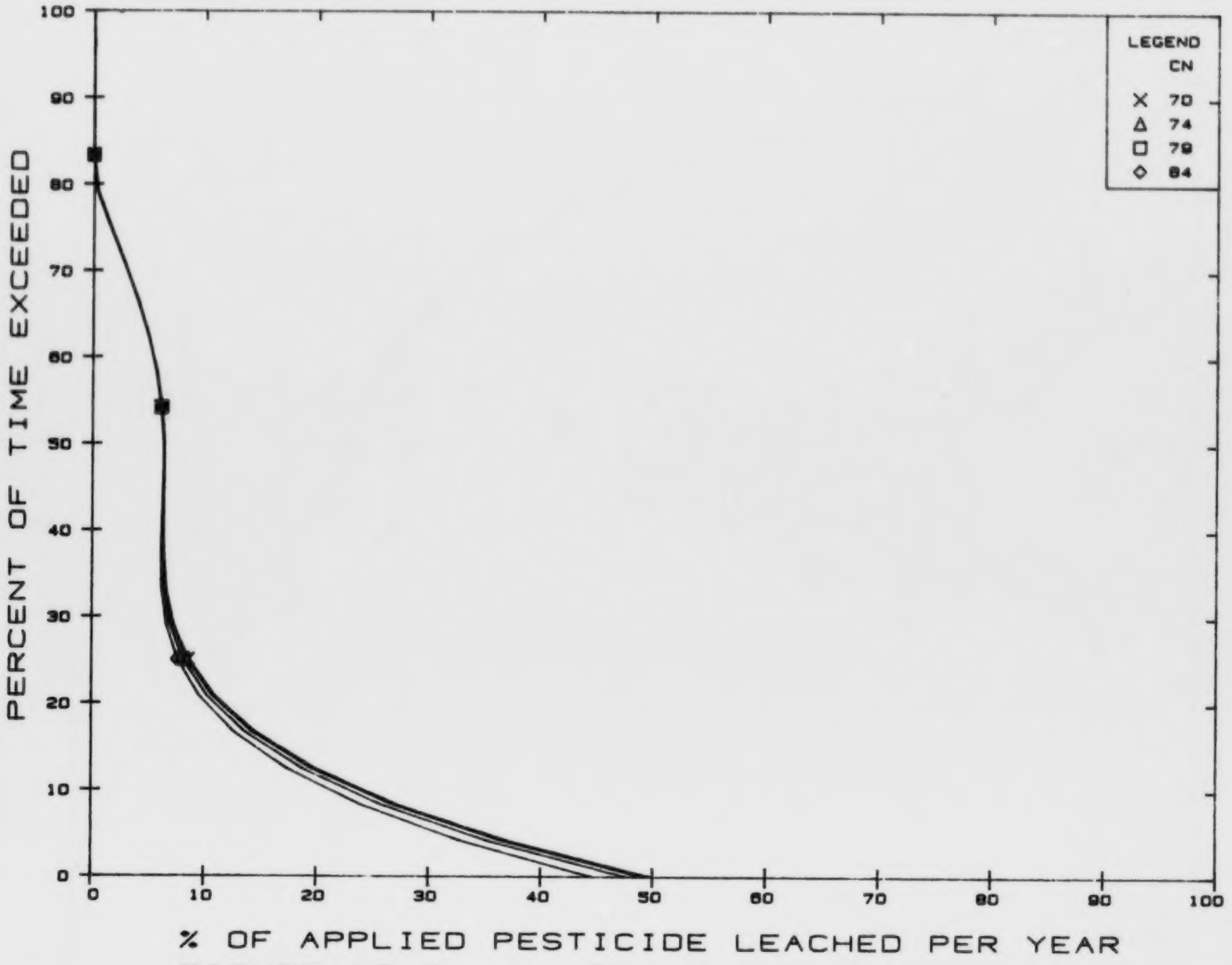


FIGURE A2-3 R=1. KS=.010

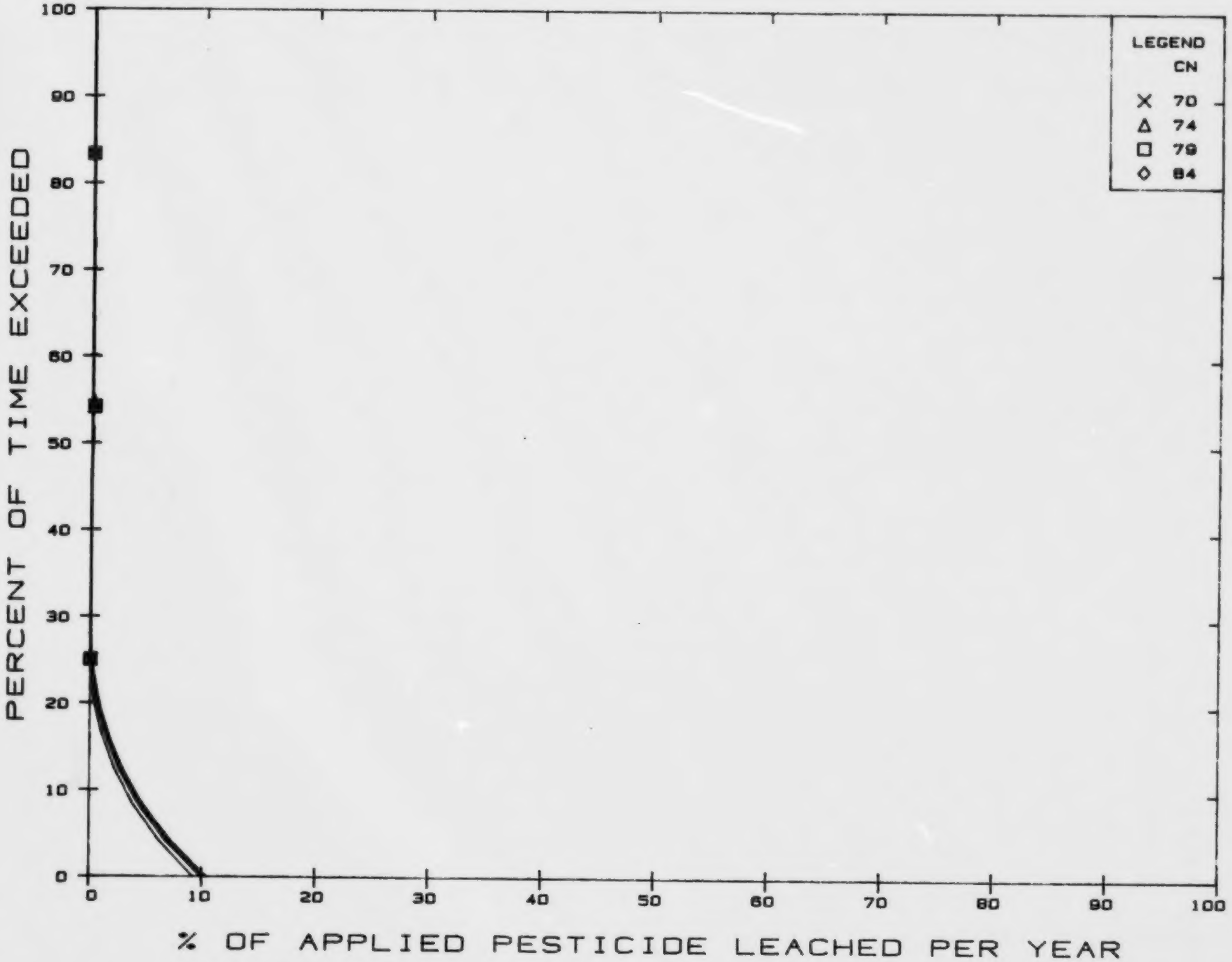


FIGURE A2-4 R=1 KS=.050

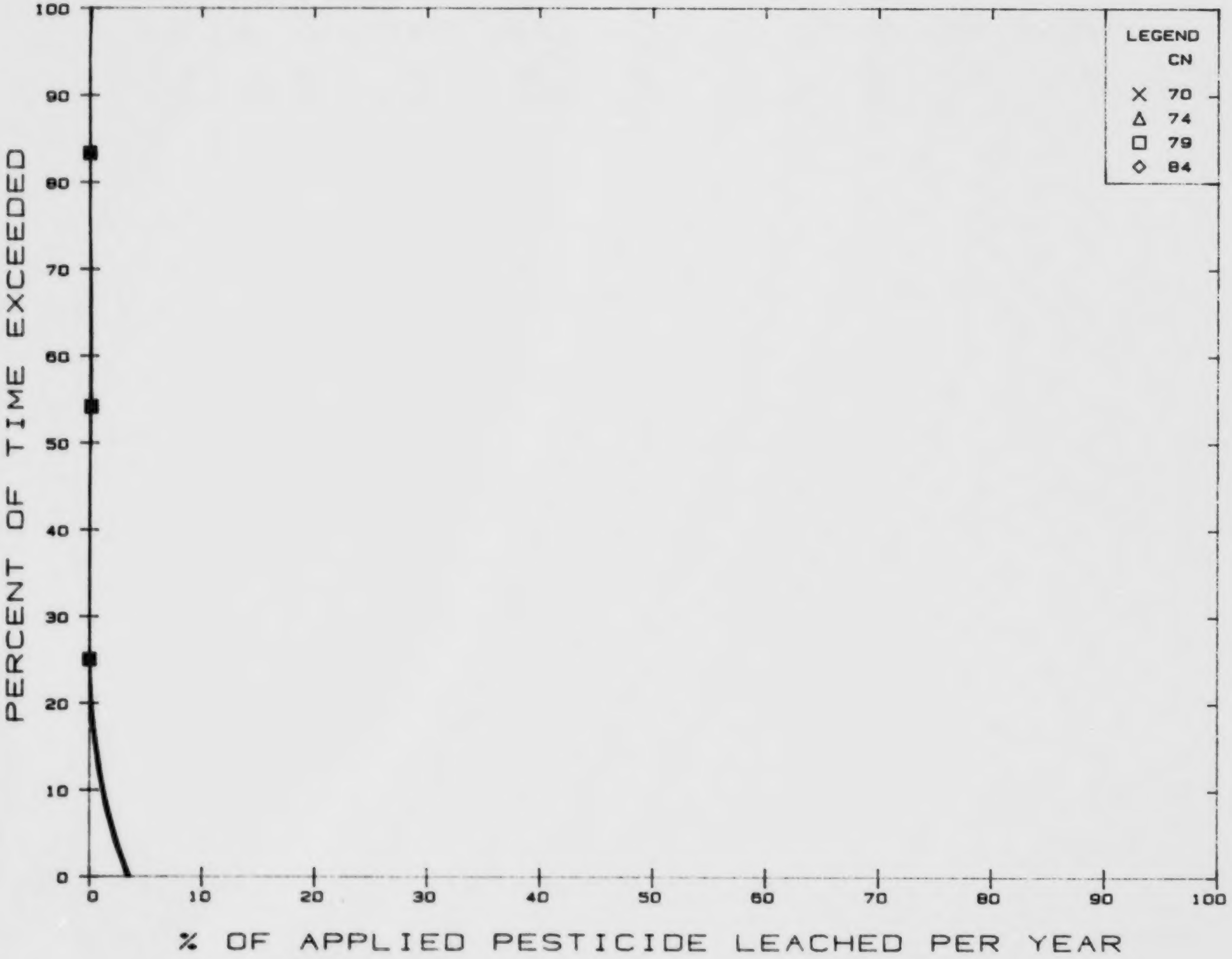


FIGURE A2-5 R=1. KS=.100

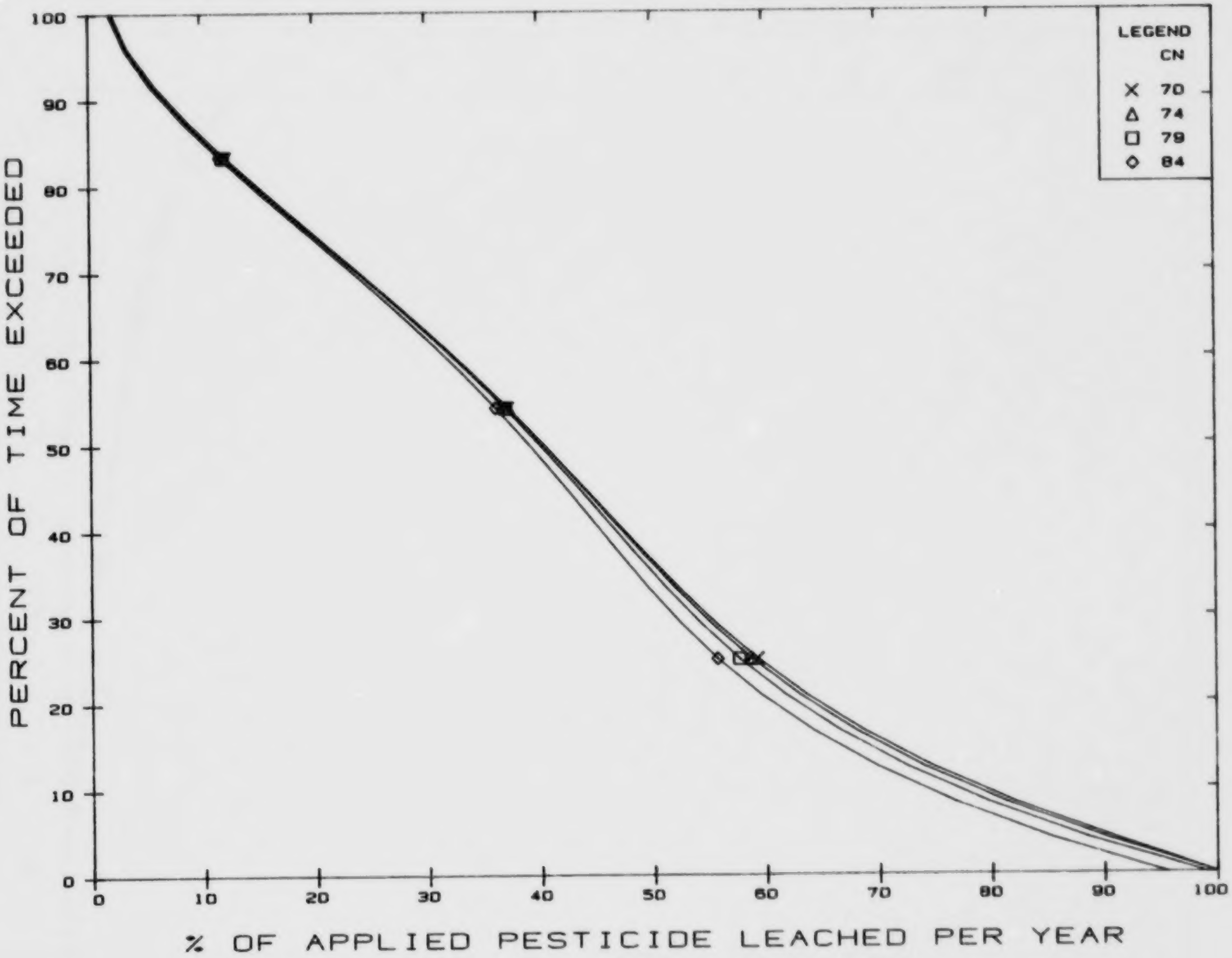


FIGURE A2-6 R=3. KS=.001

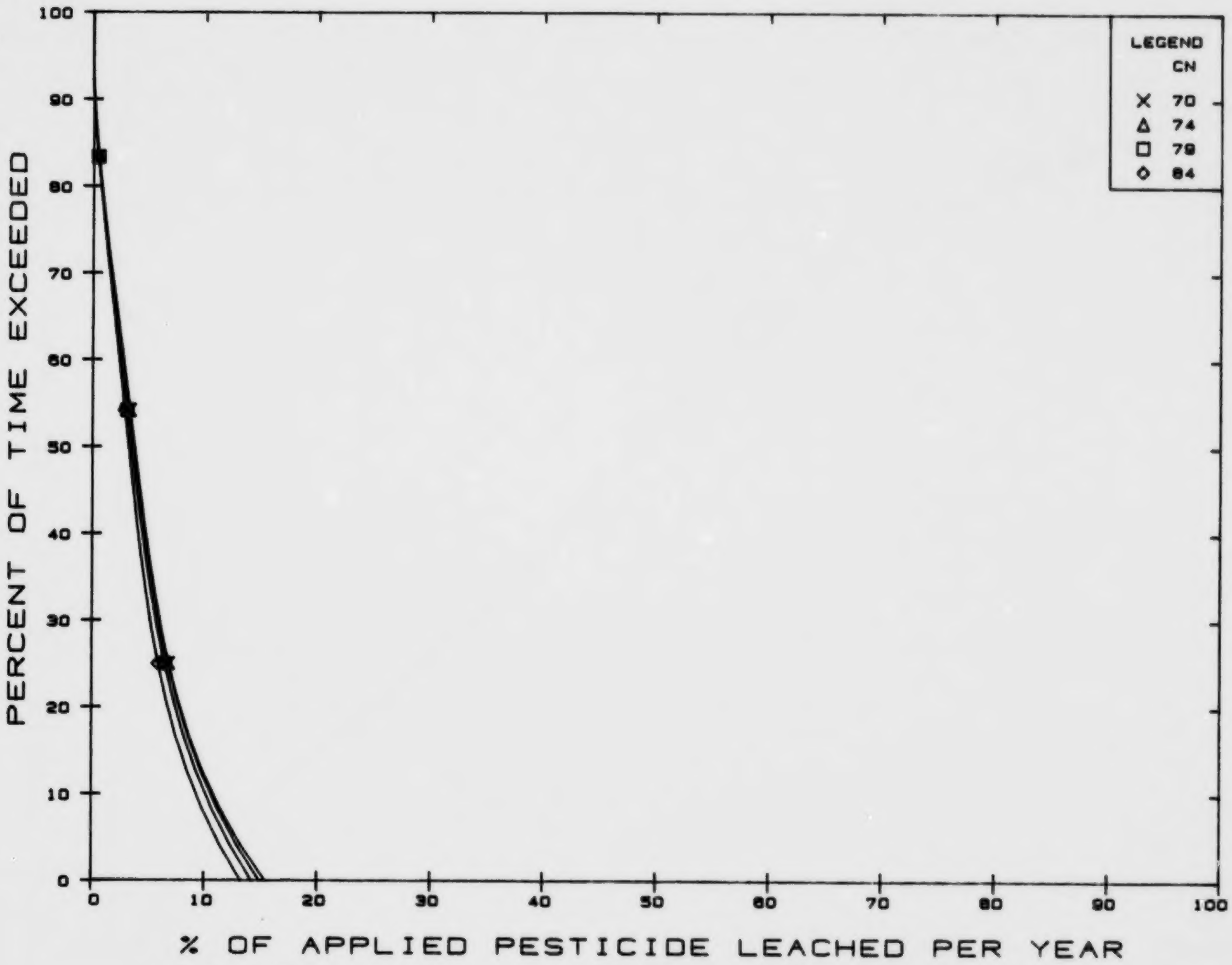


FIGURE A2-7 R=3. KS=.005

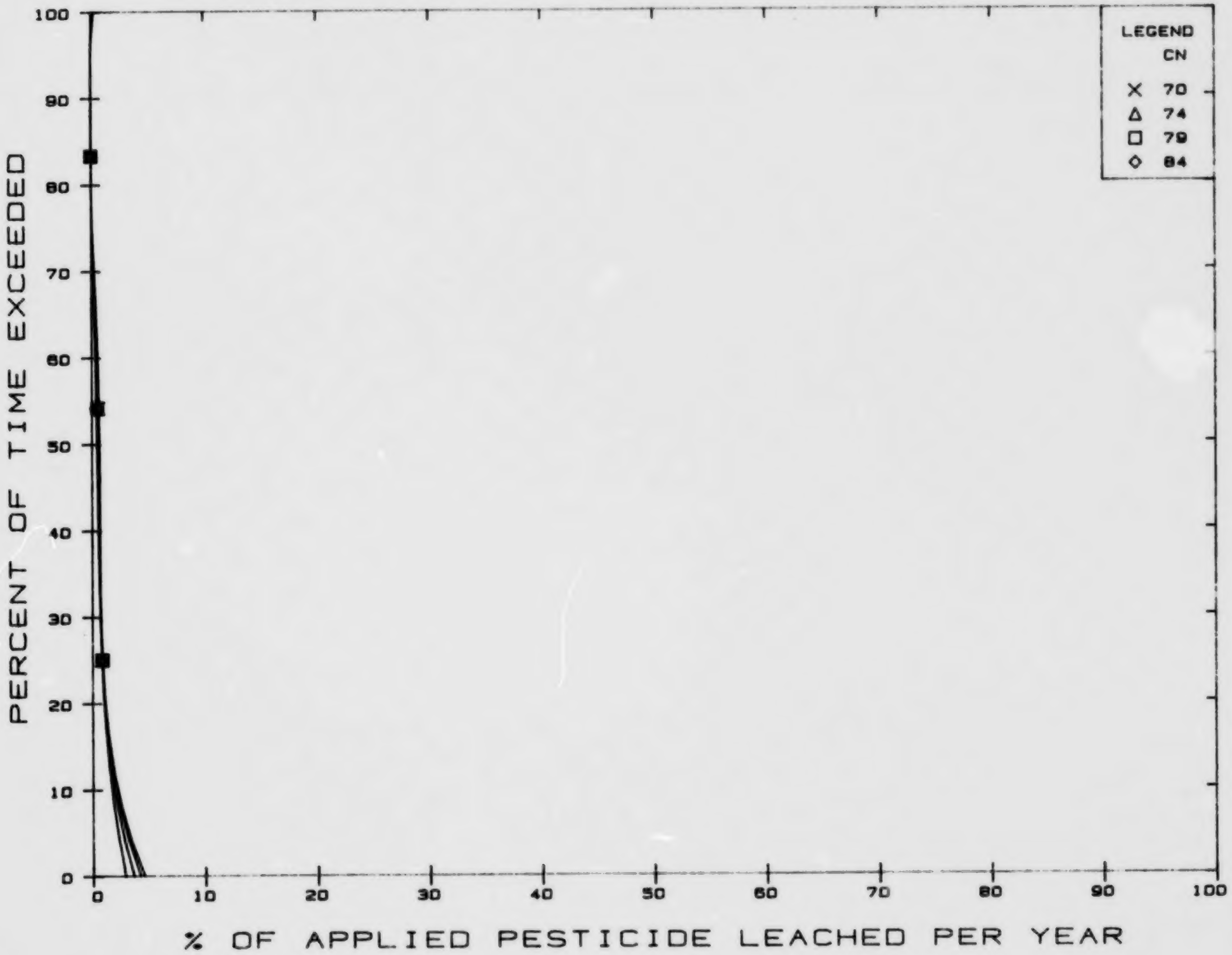


FIGURE A2-8 R=3. KS=.010

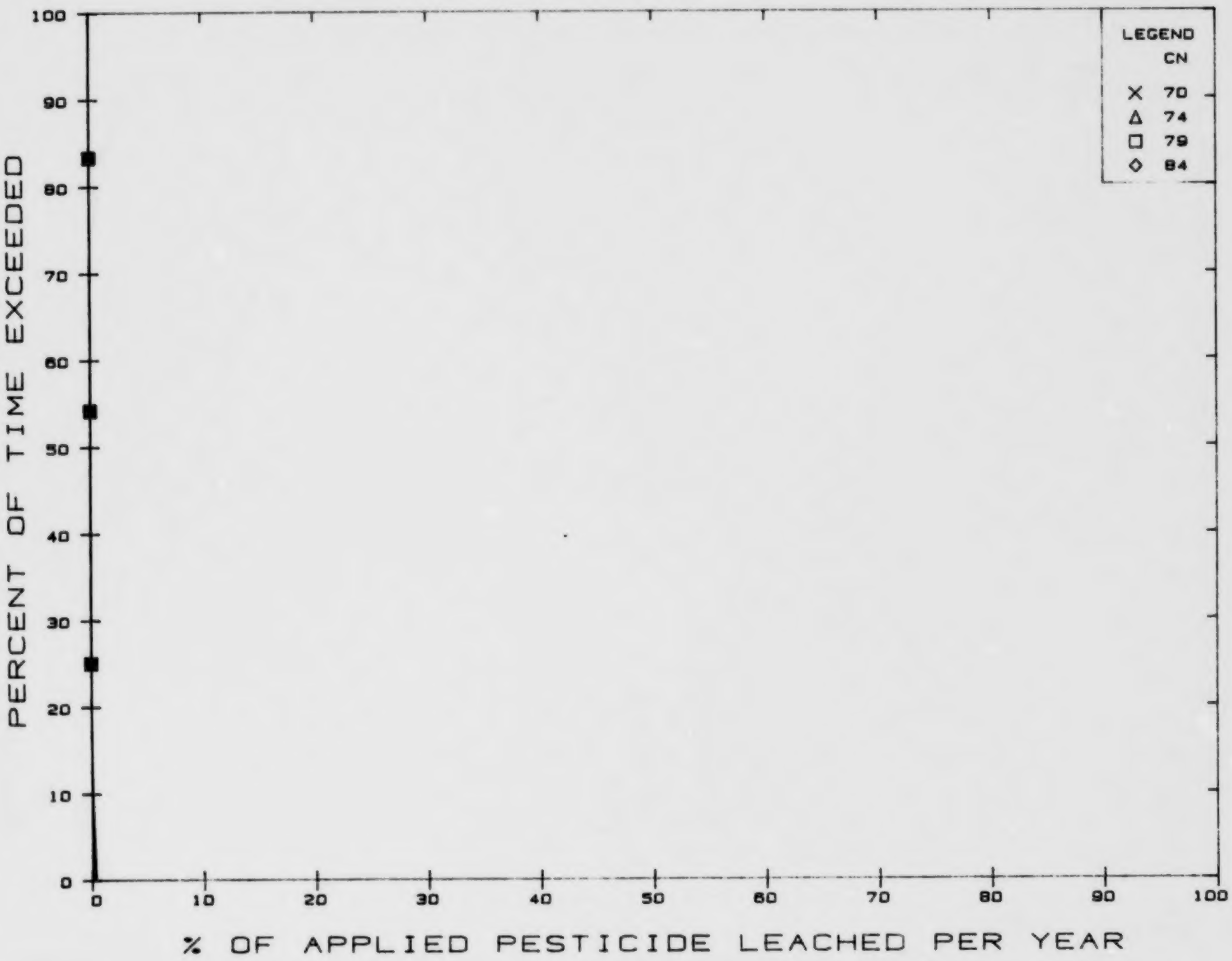


FIGURE A2-9 R=3. KS=.050

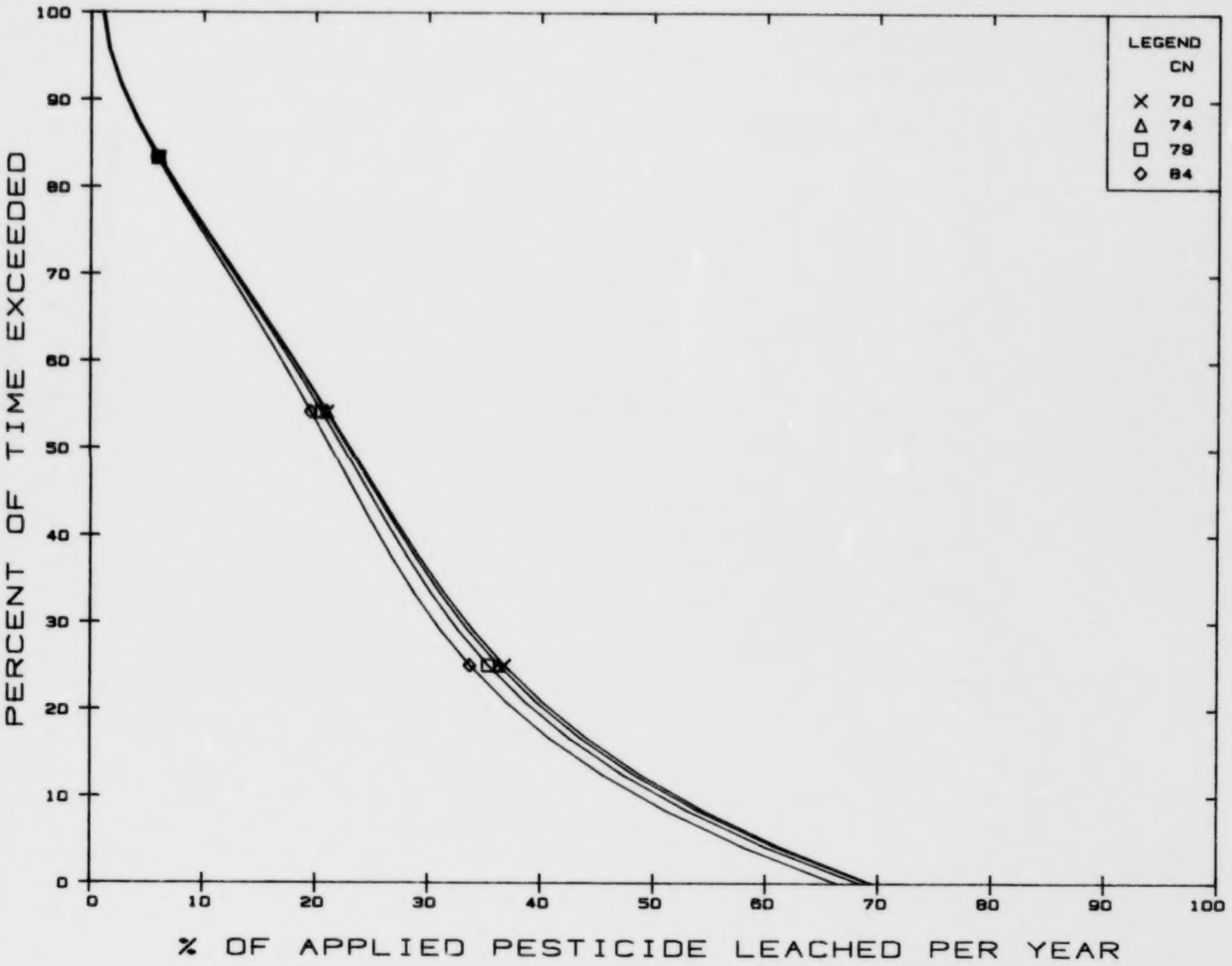
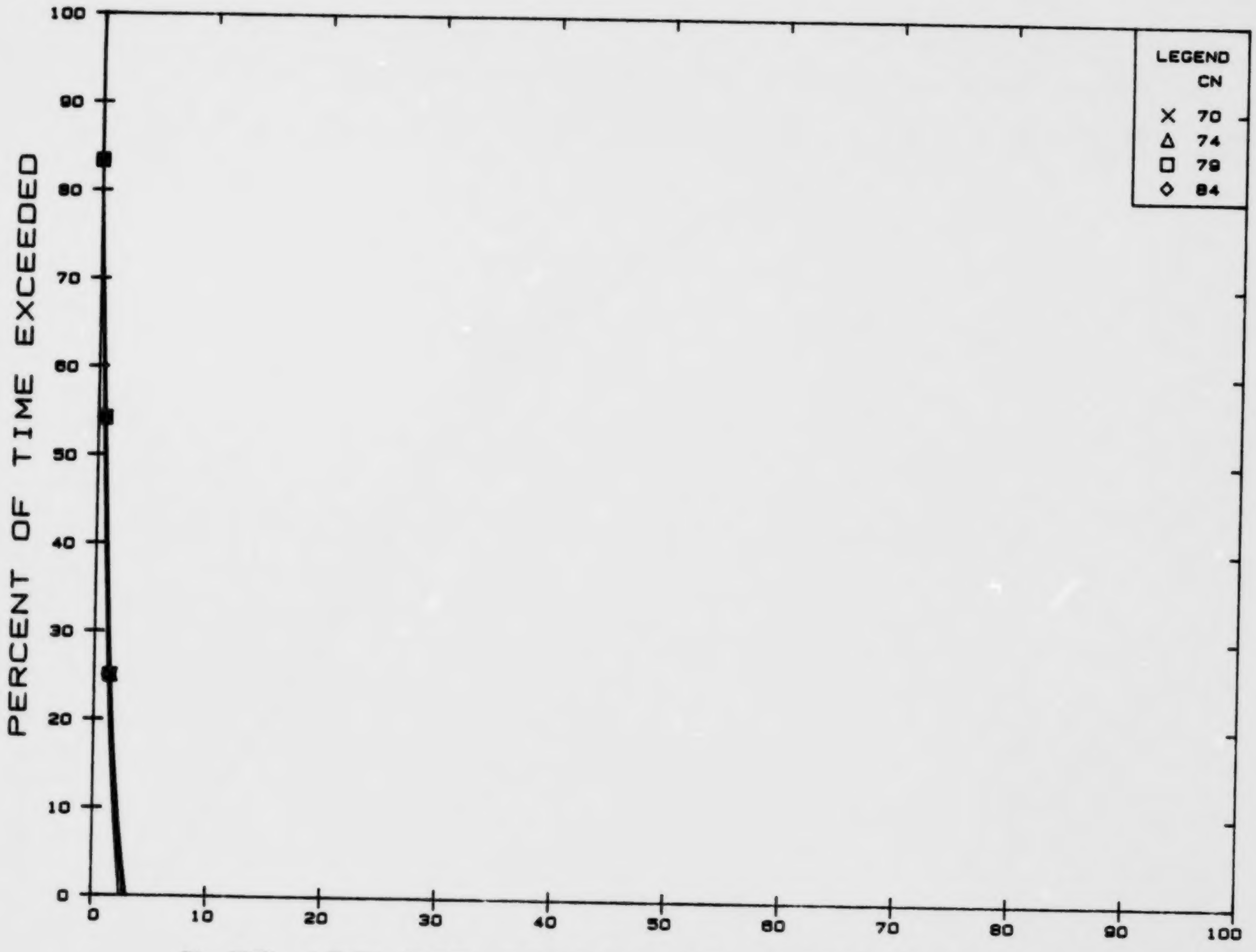


FIGURE A2-10 R=5. KS=.001



% OF APPLIED PESTICIDE LEACHED PER YEAR
FIGURE A2-11 R=5. KS=.005

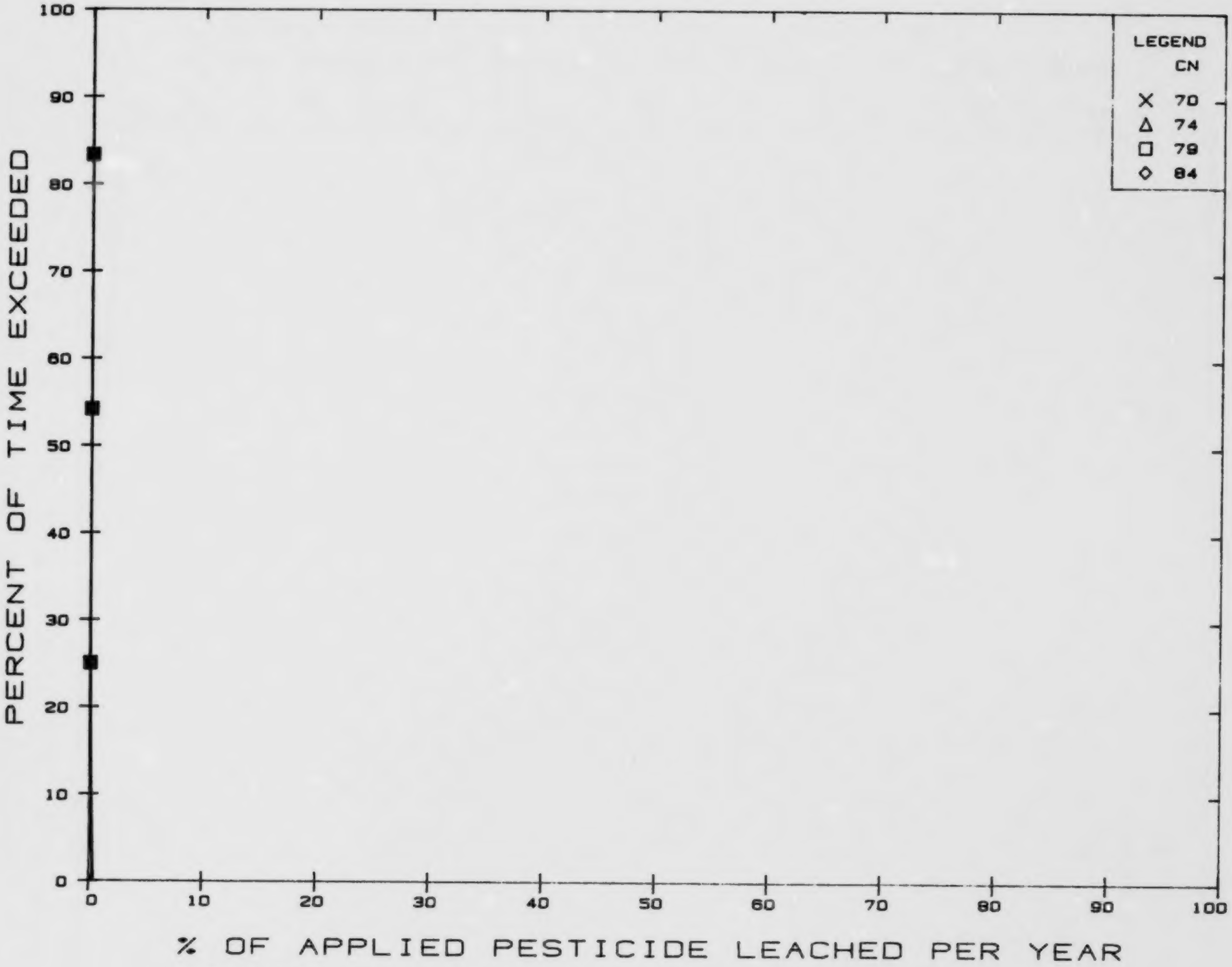


FIGURE A2-12 R=5. KS=.010

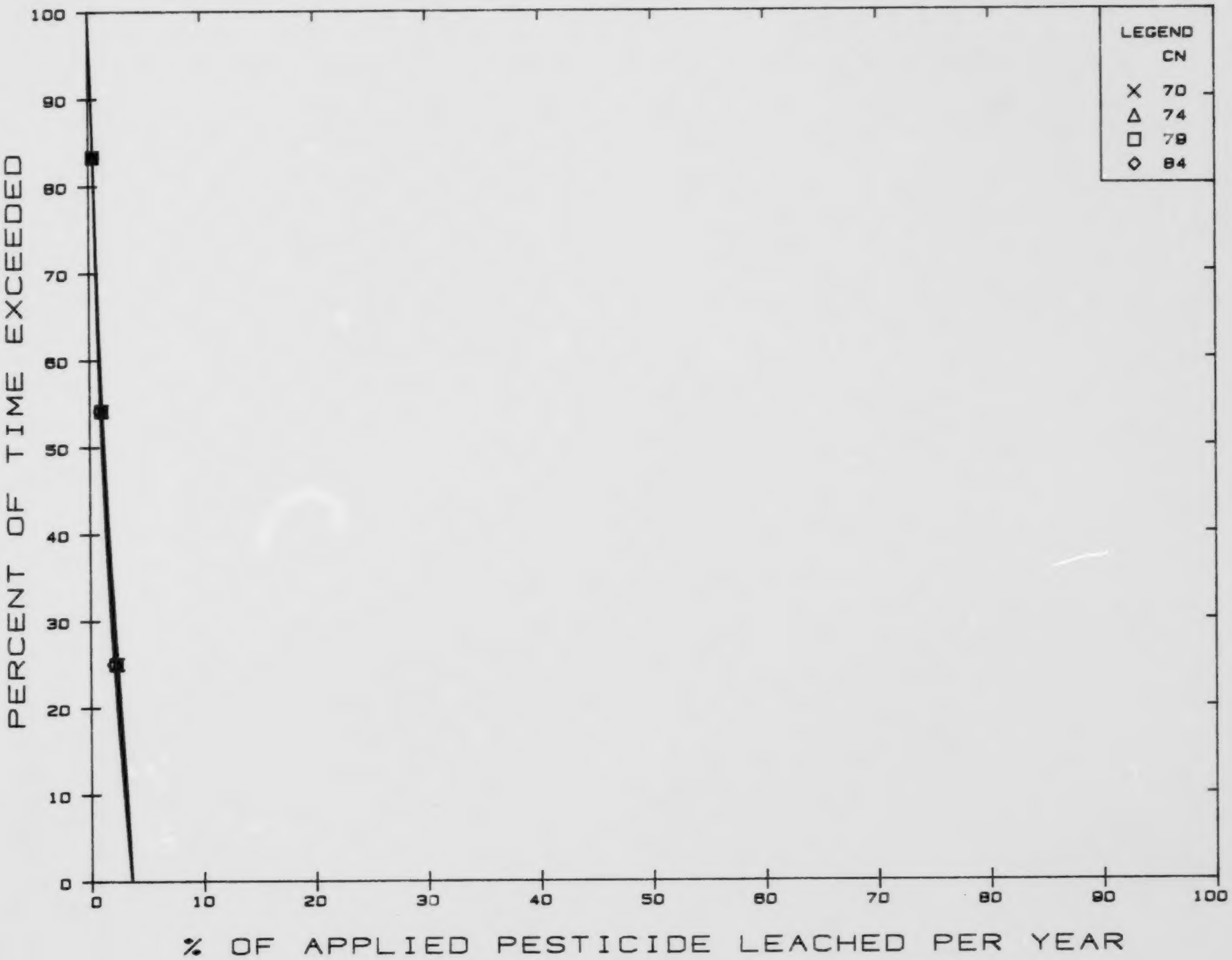


FIGURE A2-13 R=20. KS=.001

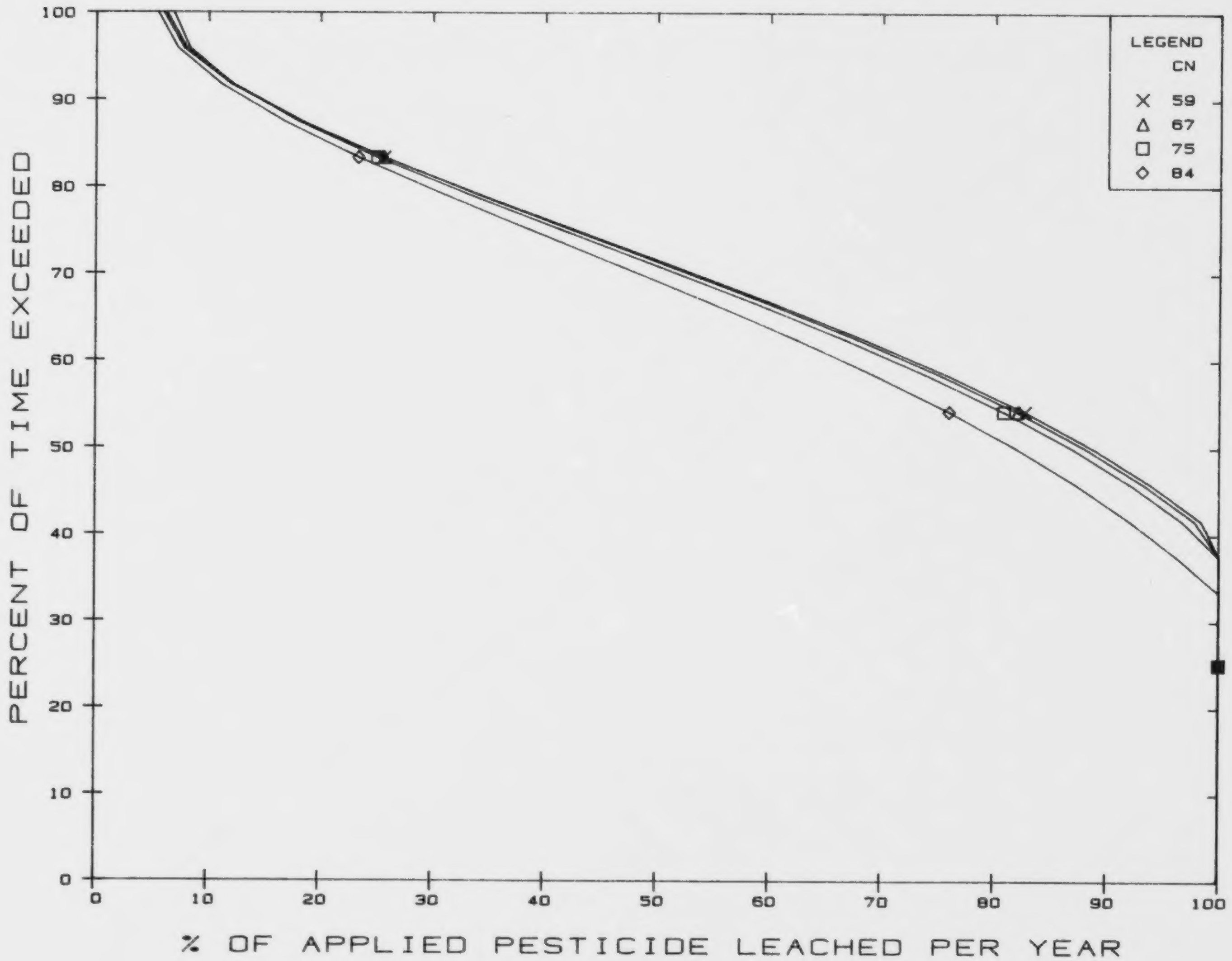


FIGURE A3-1 R=1. KS=.001

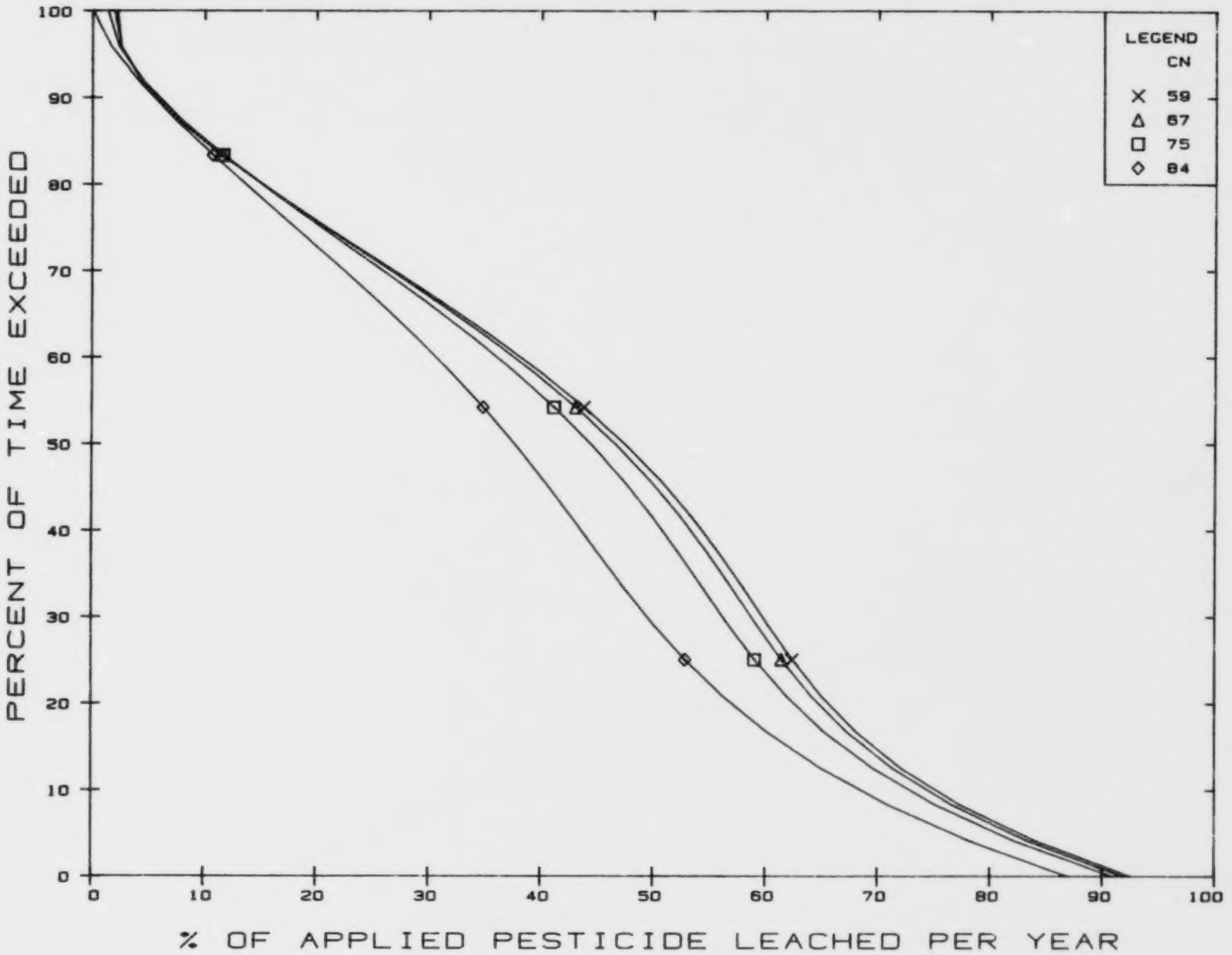


FIGURE A3-2 R=1. KS=.005

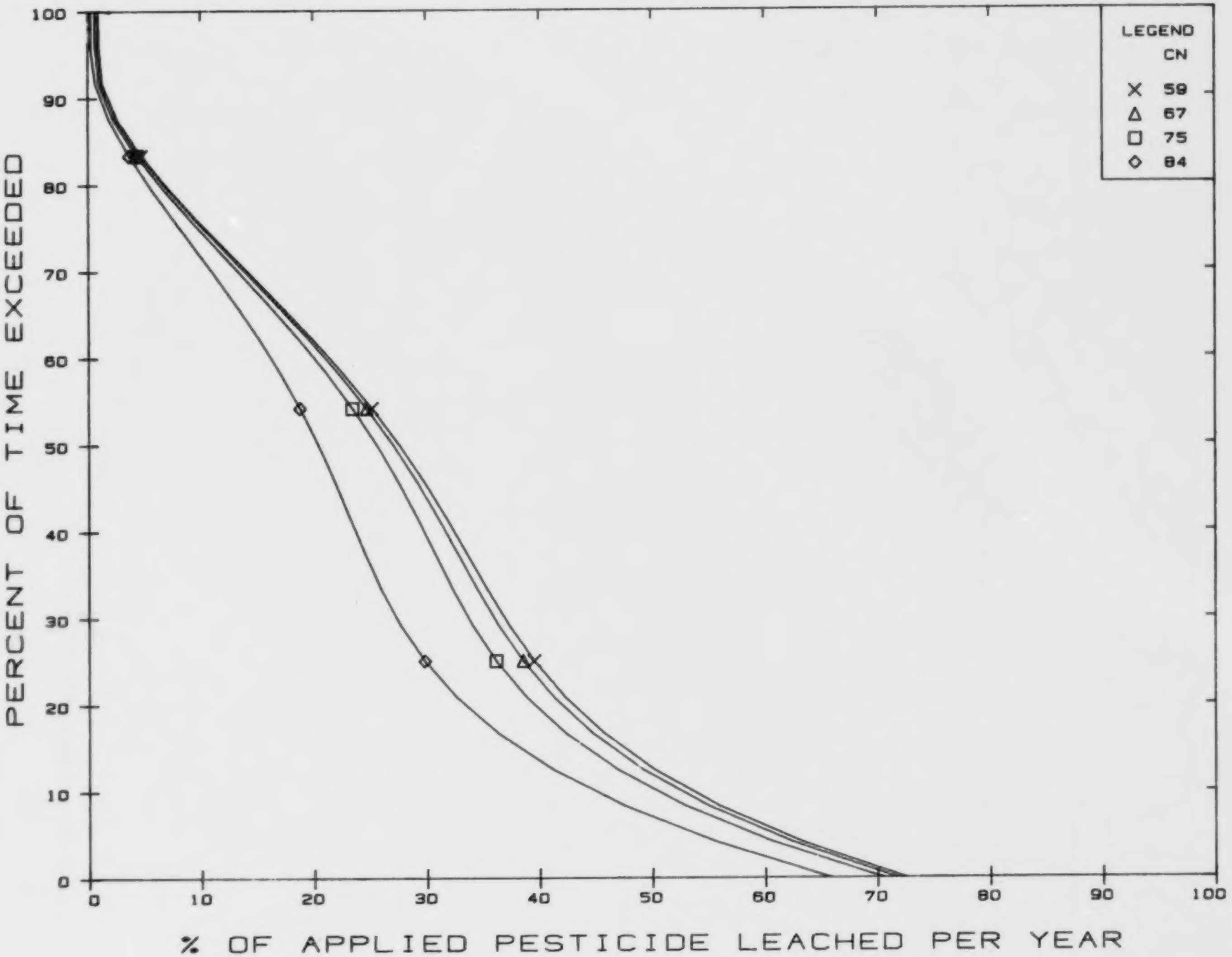


FIGURE A3-3 R=1. KS=.010

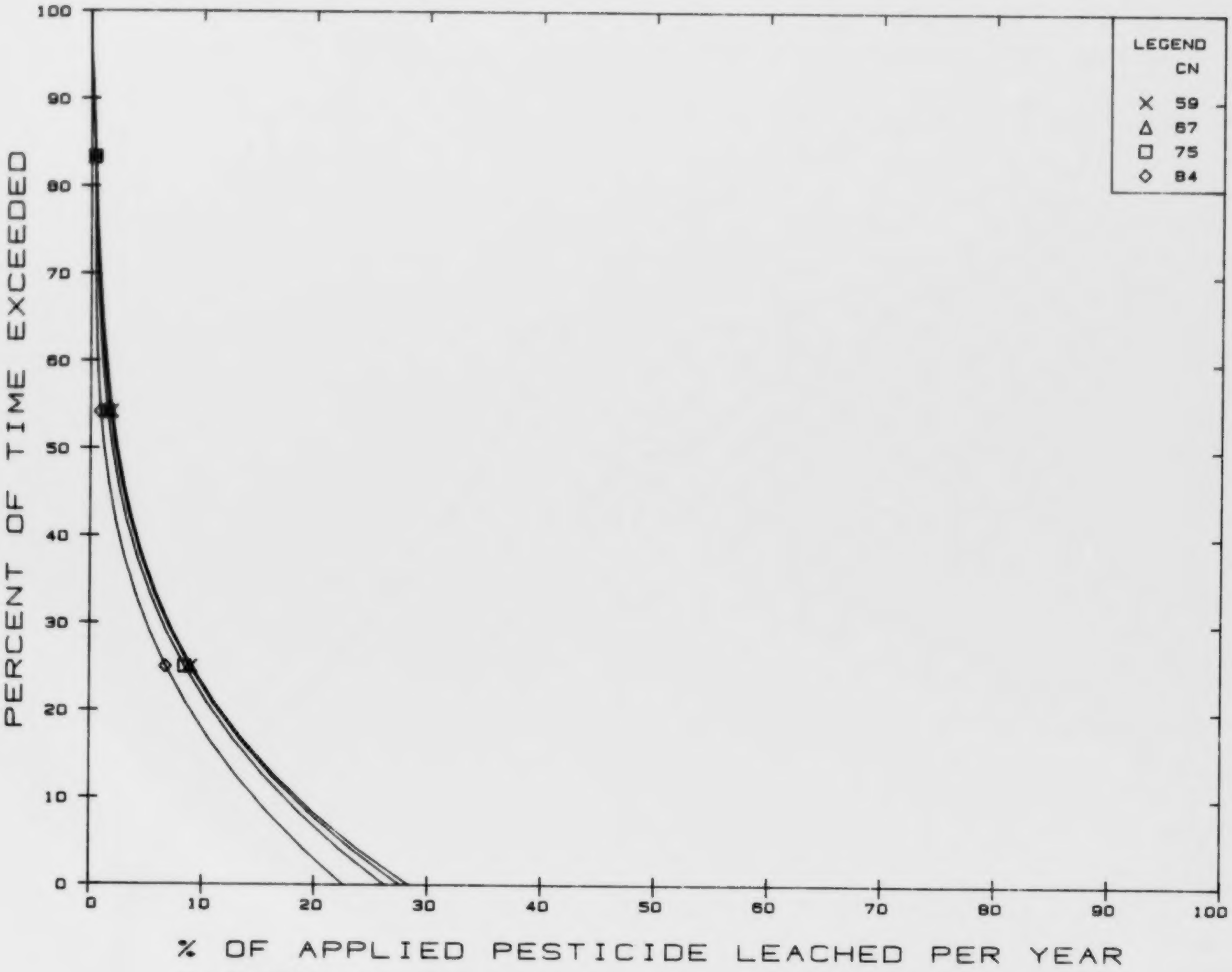


FIGURE A3-4 R=1. KS=.050

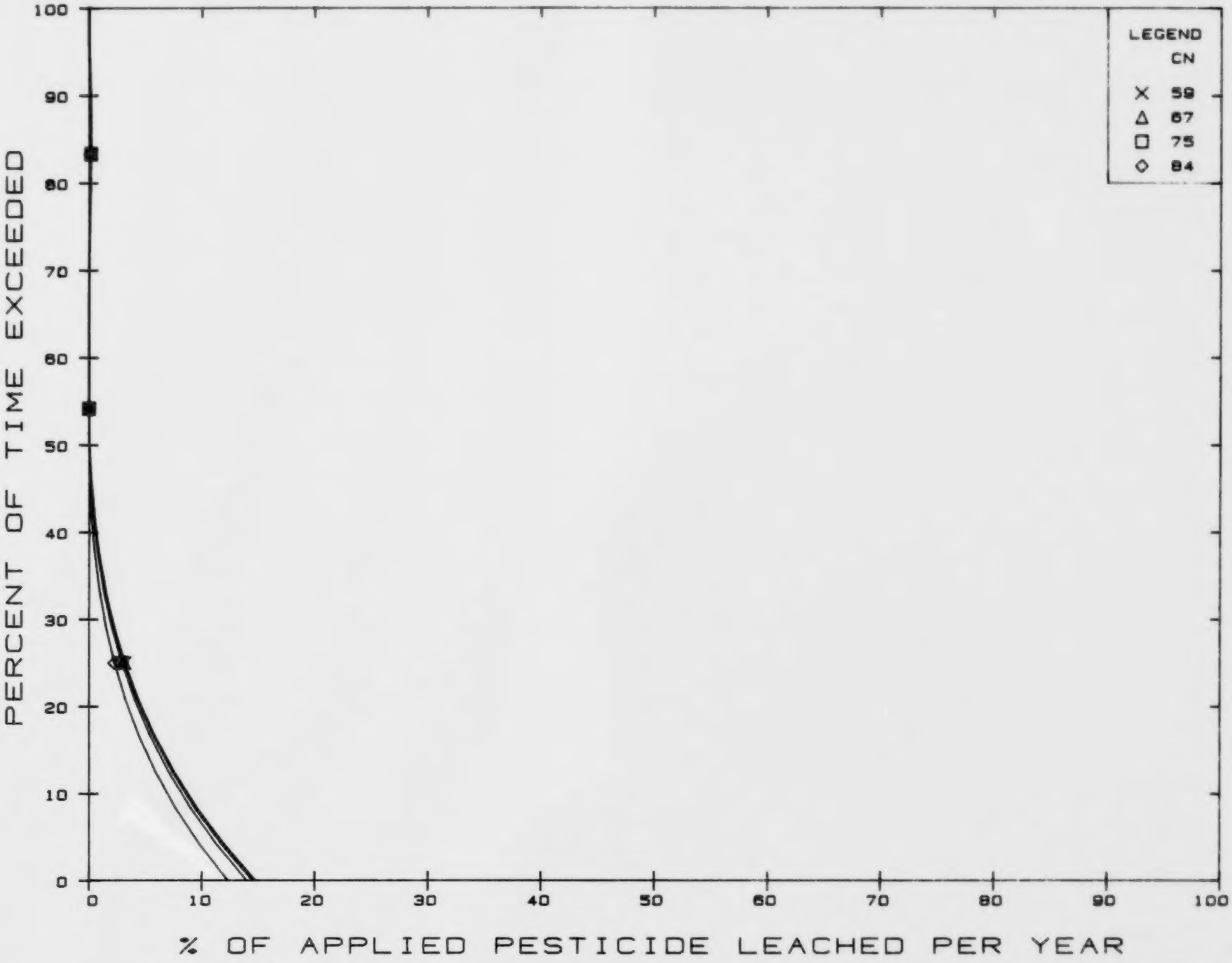


FIGURE A3-5 R=1. KS=.100

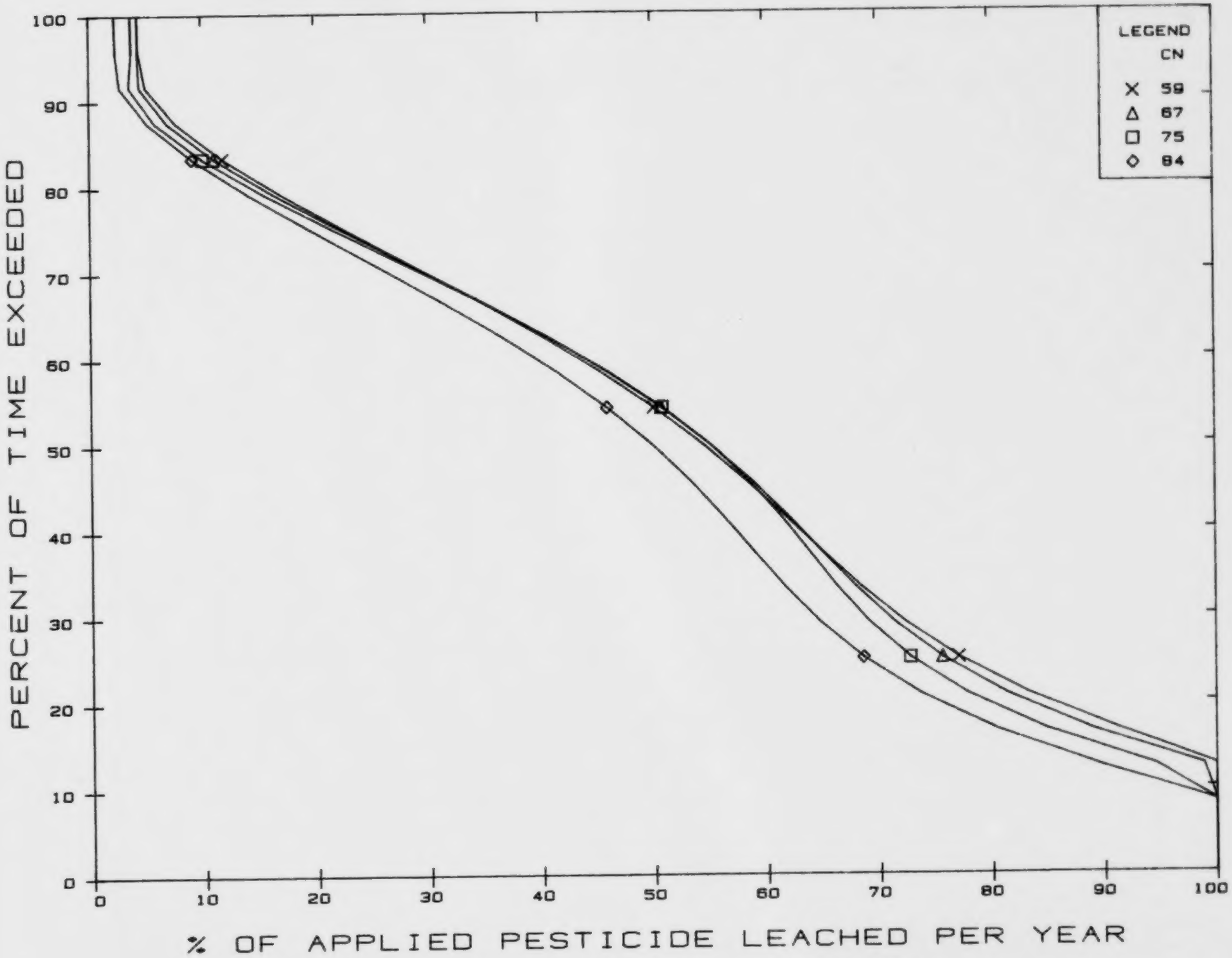


FIGURE A3-6 R=3. KS=.001

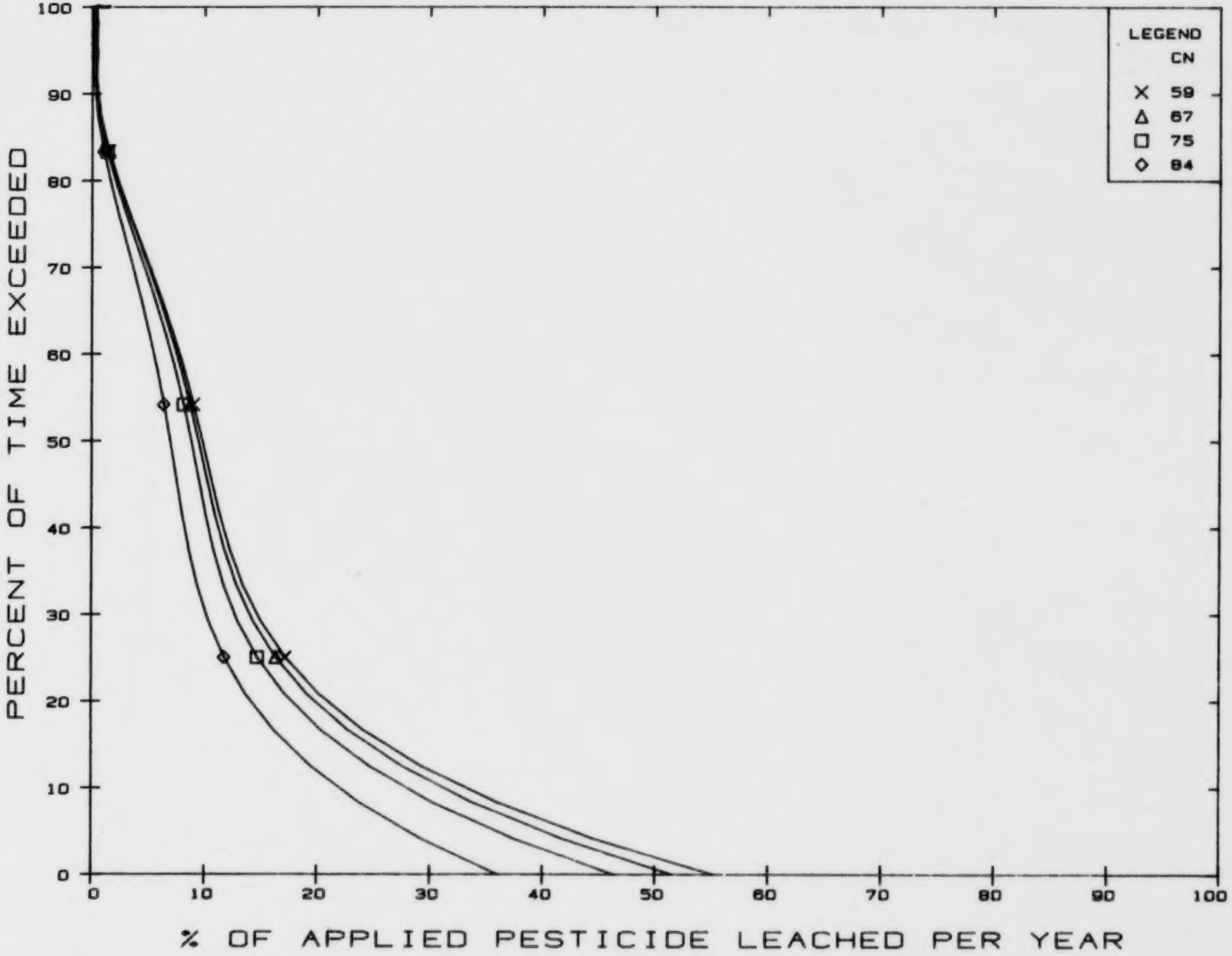


FIGURE A3-7 R=3. KS=.005

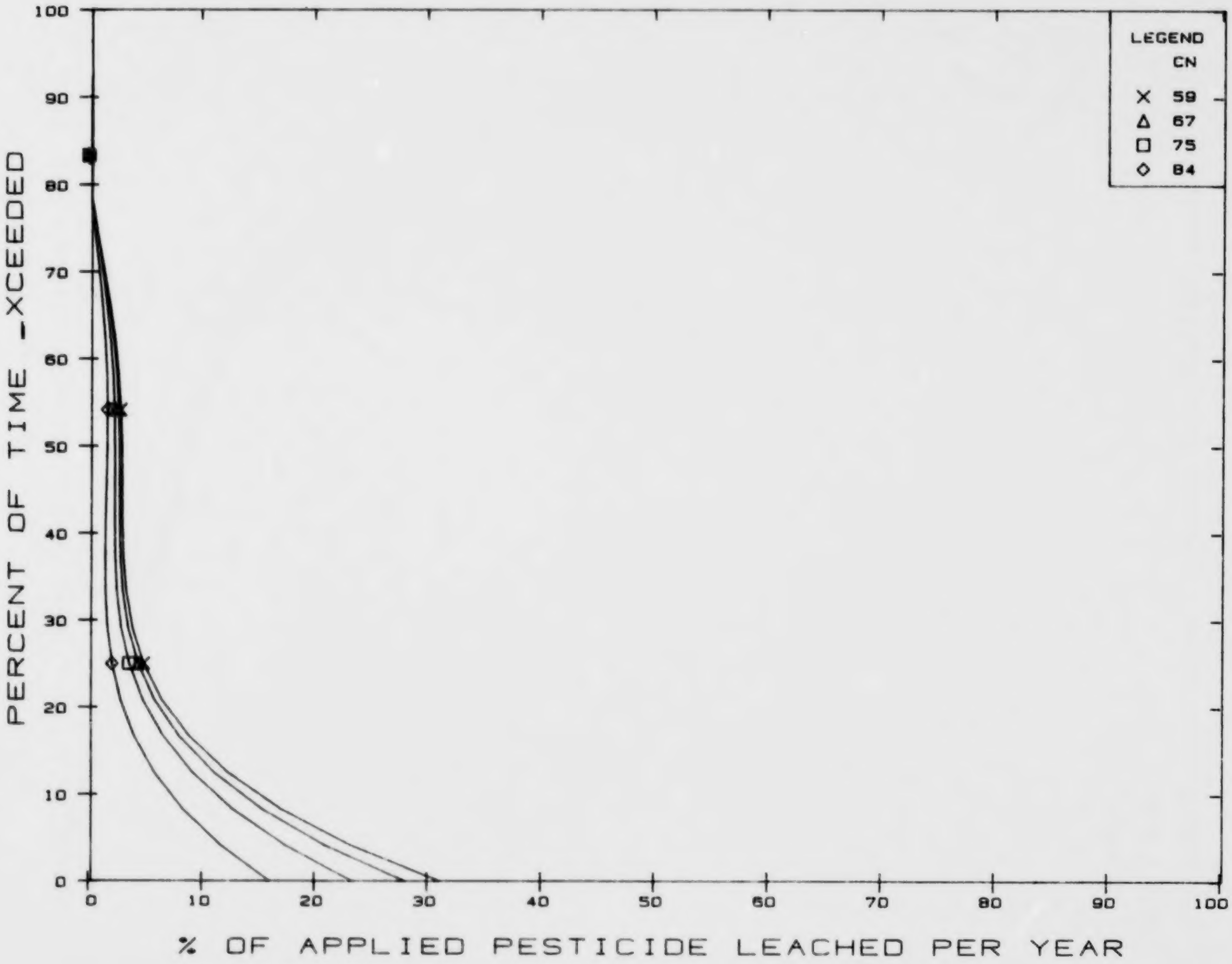


FIGURE A3-8 R=3. KS=.010

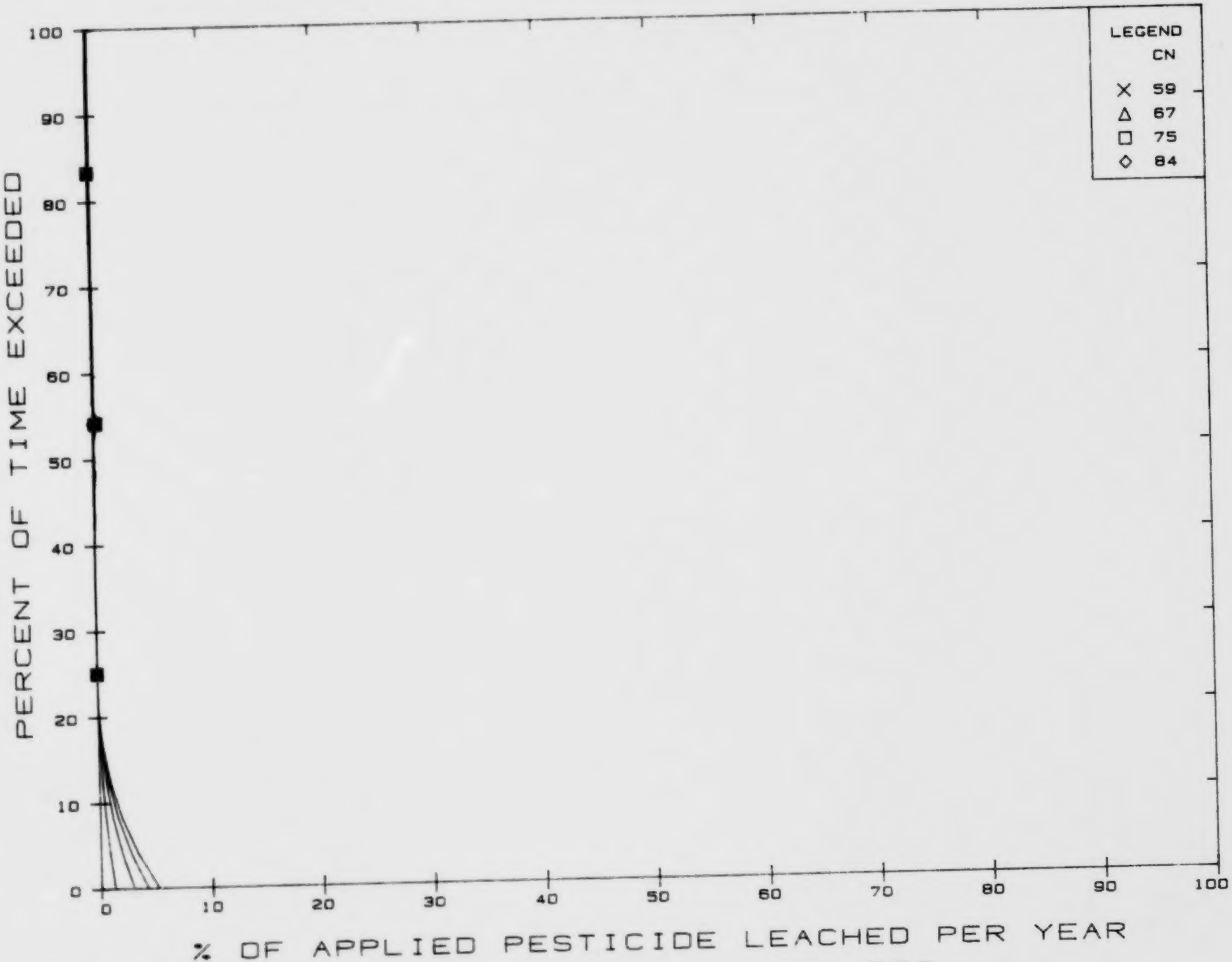


FIGURE A3-9 R=3. KS=.050

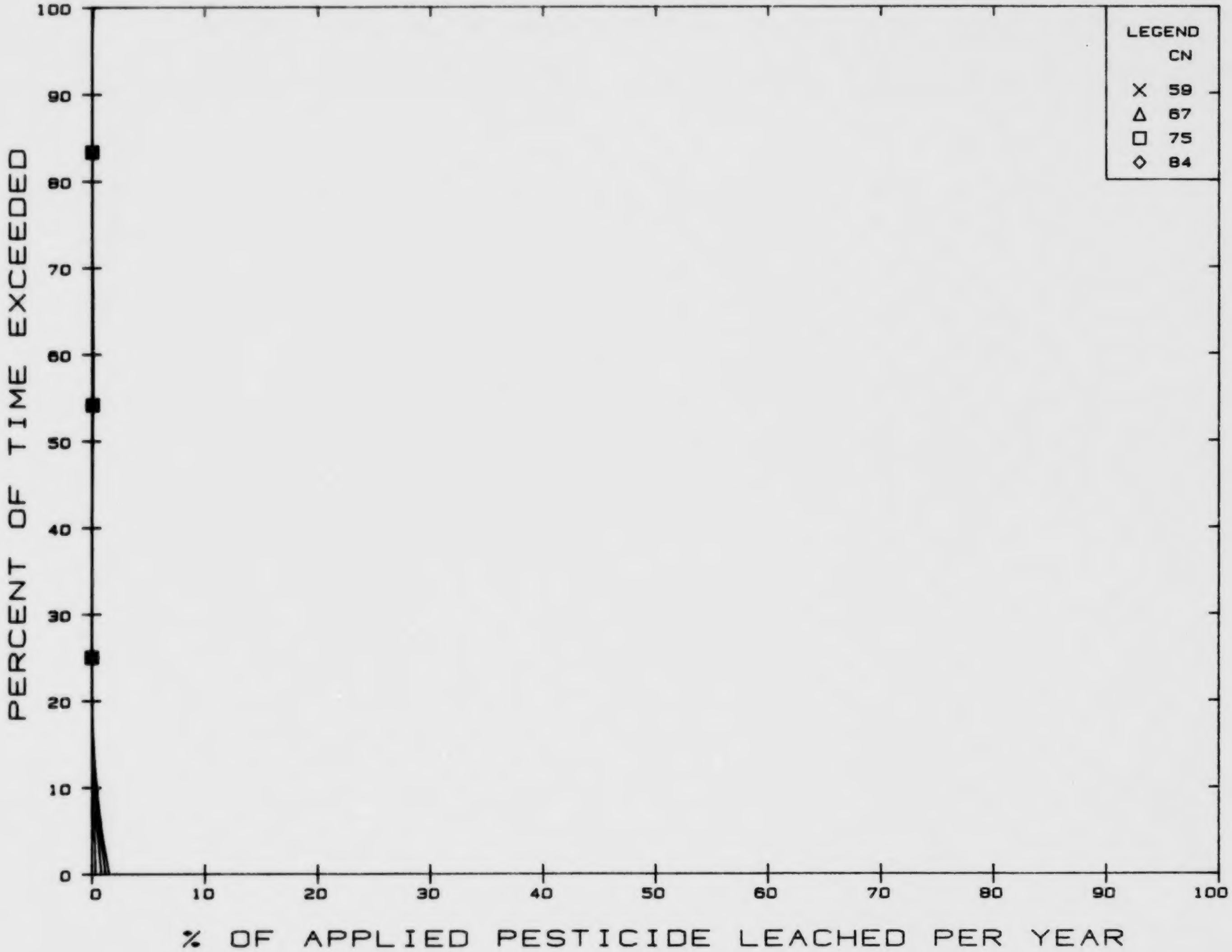


FIGURE A3-10 R=3. KS=.100

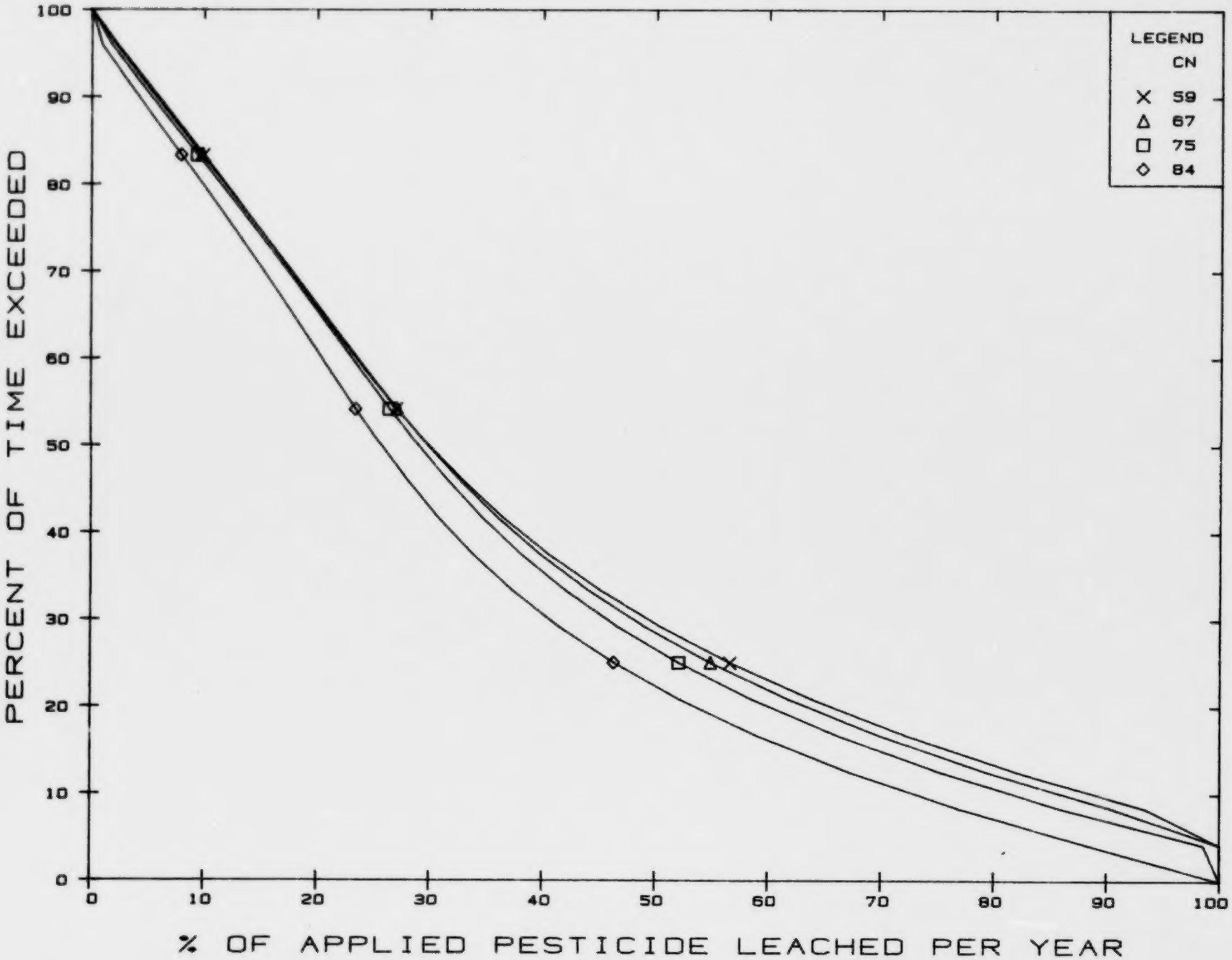


FIGURE A3-11 R=5. KS=.001

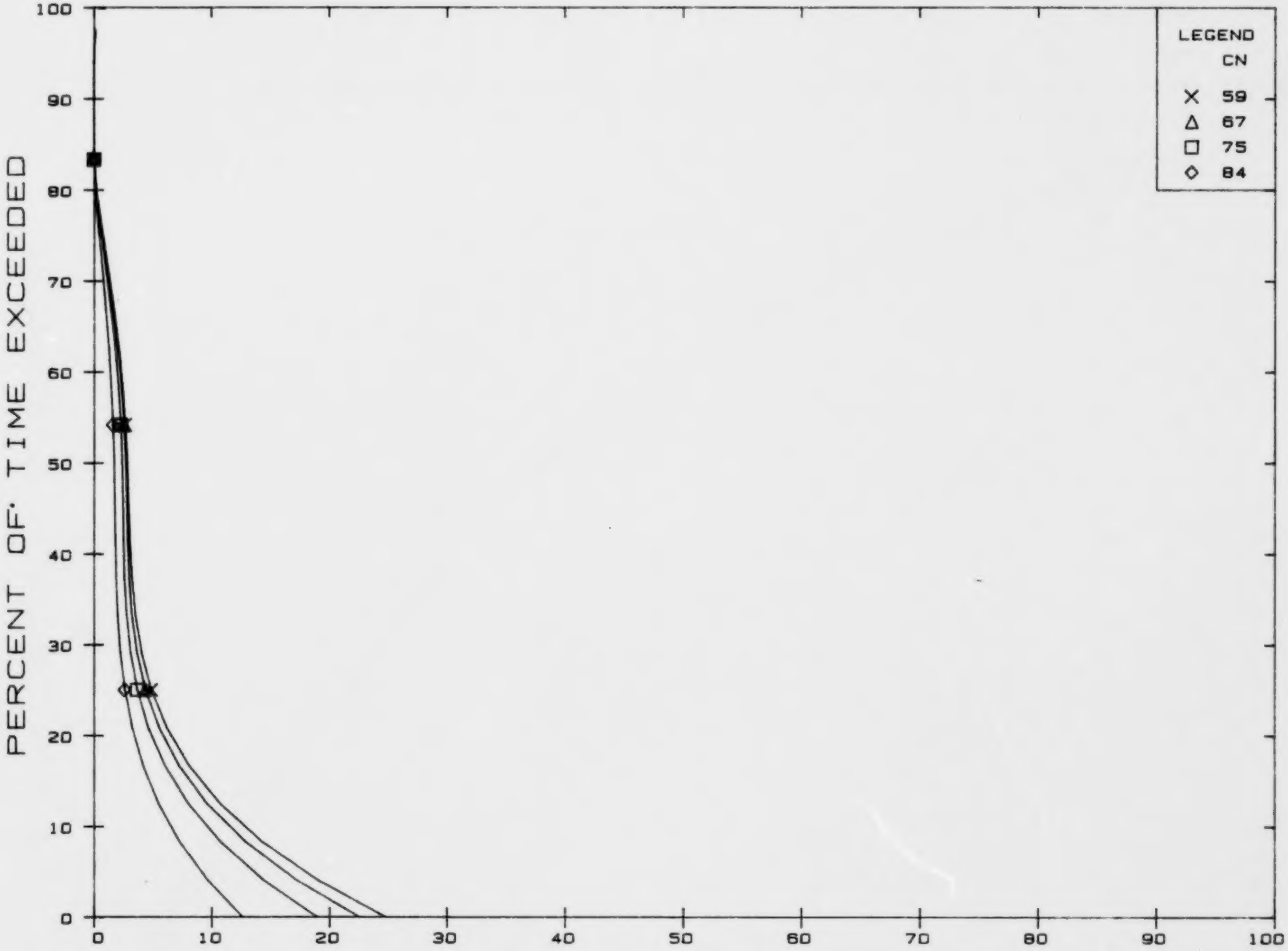


FIGURE A3-12 R=5. KS=.005

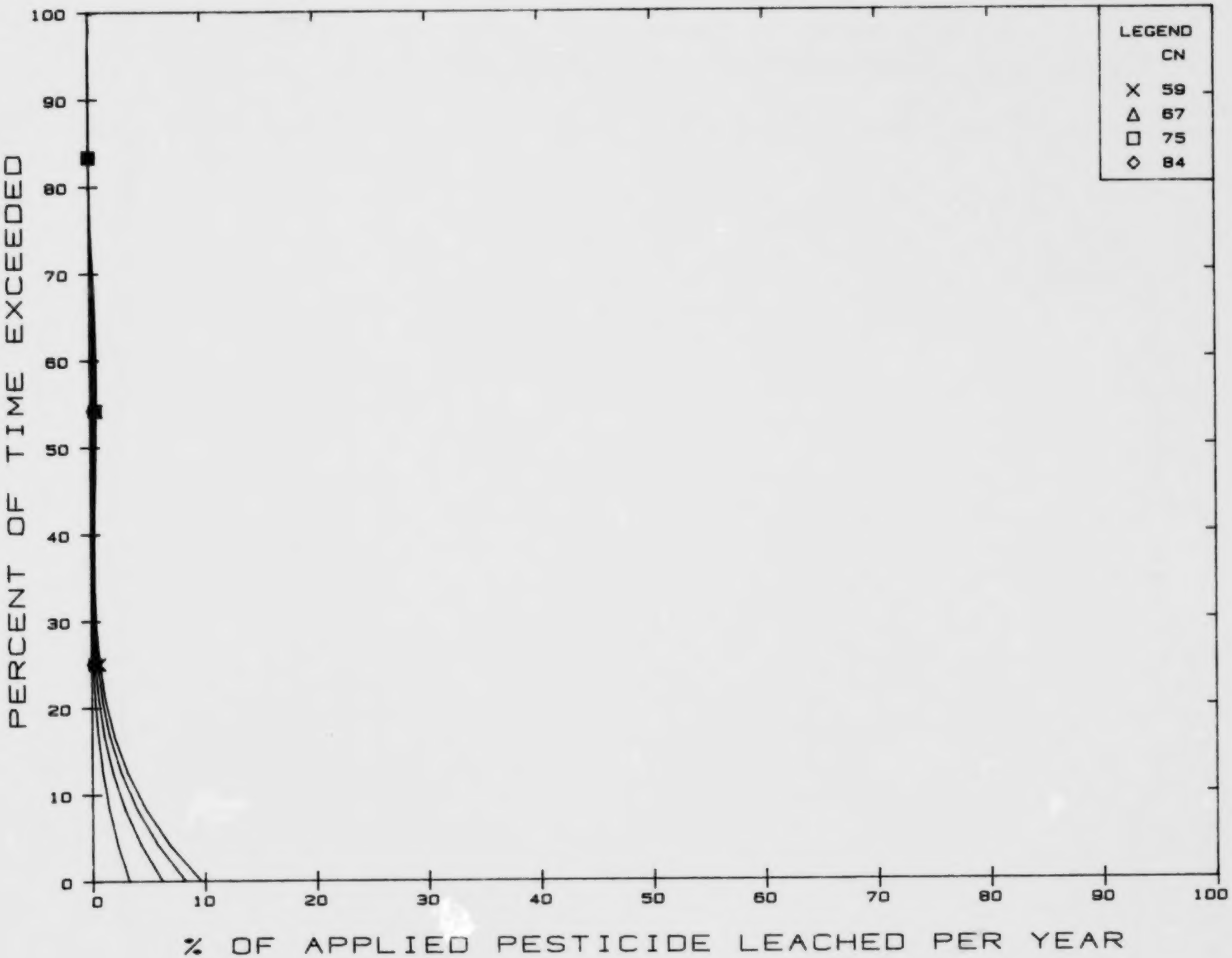


FIGURE A3-13 R=5. KS=.010

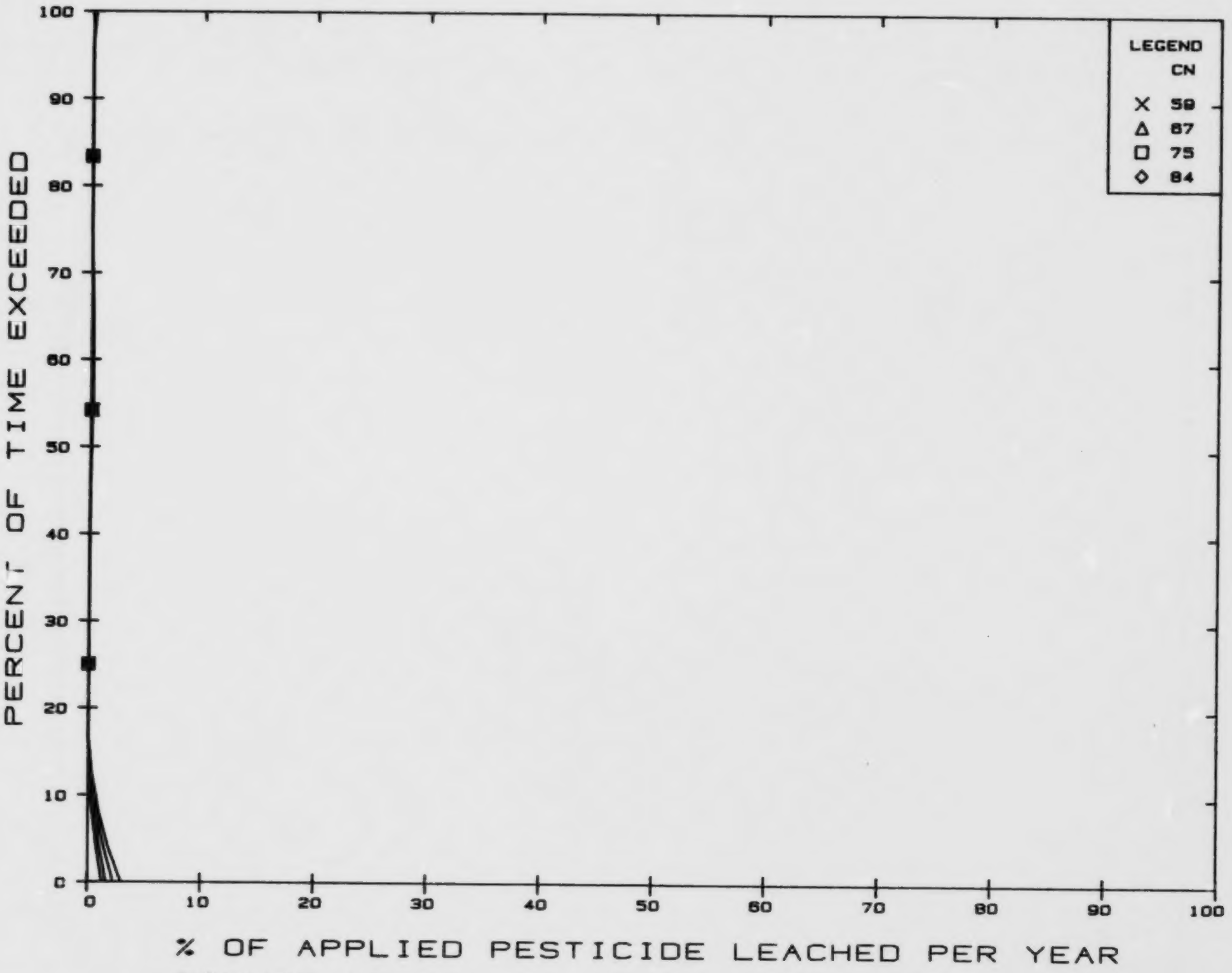


FIGURE A3-14 R=5. KS=.050

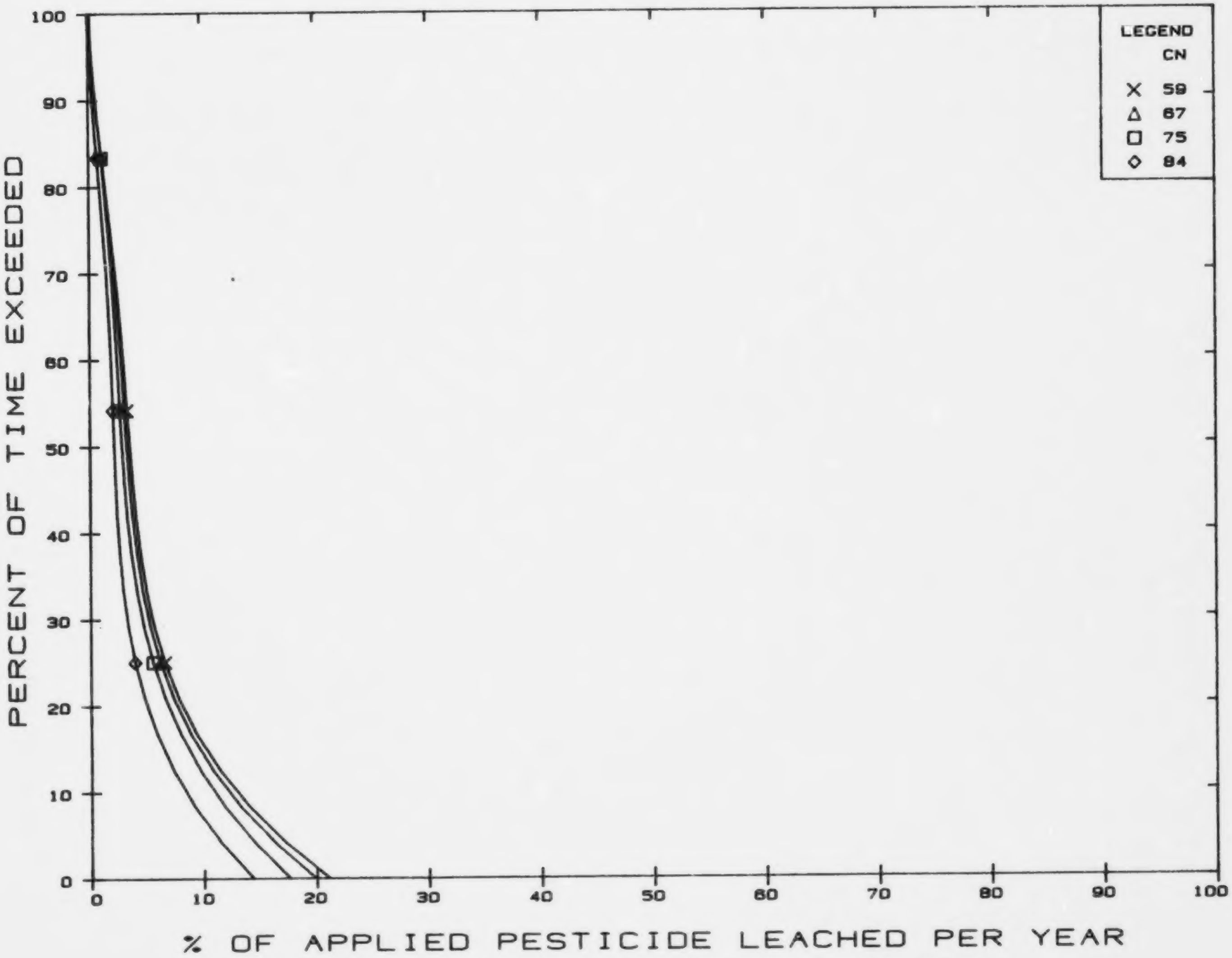


FIGURE A3-15 R=20. KS=.001

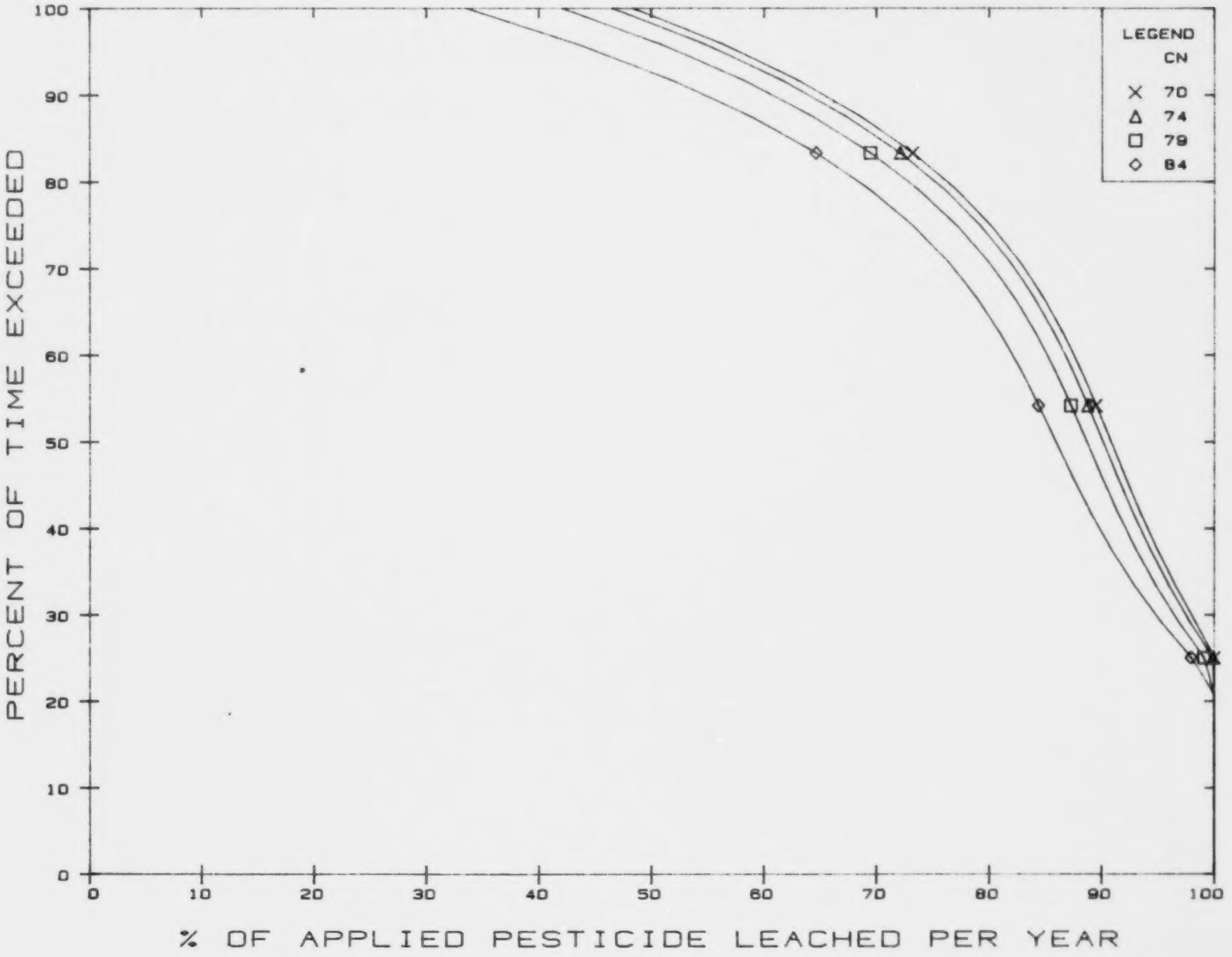


FIGURE A4-1 R=1. KS=.001

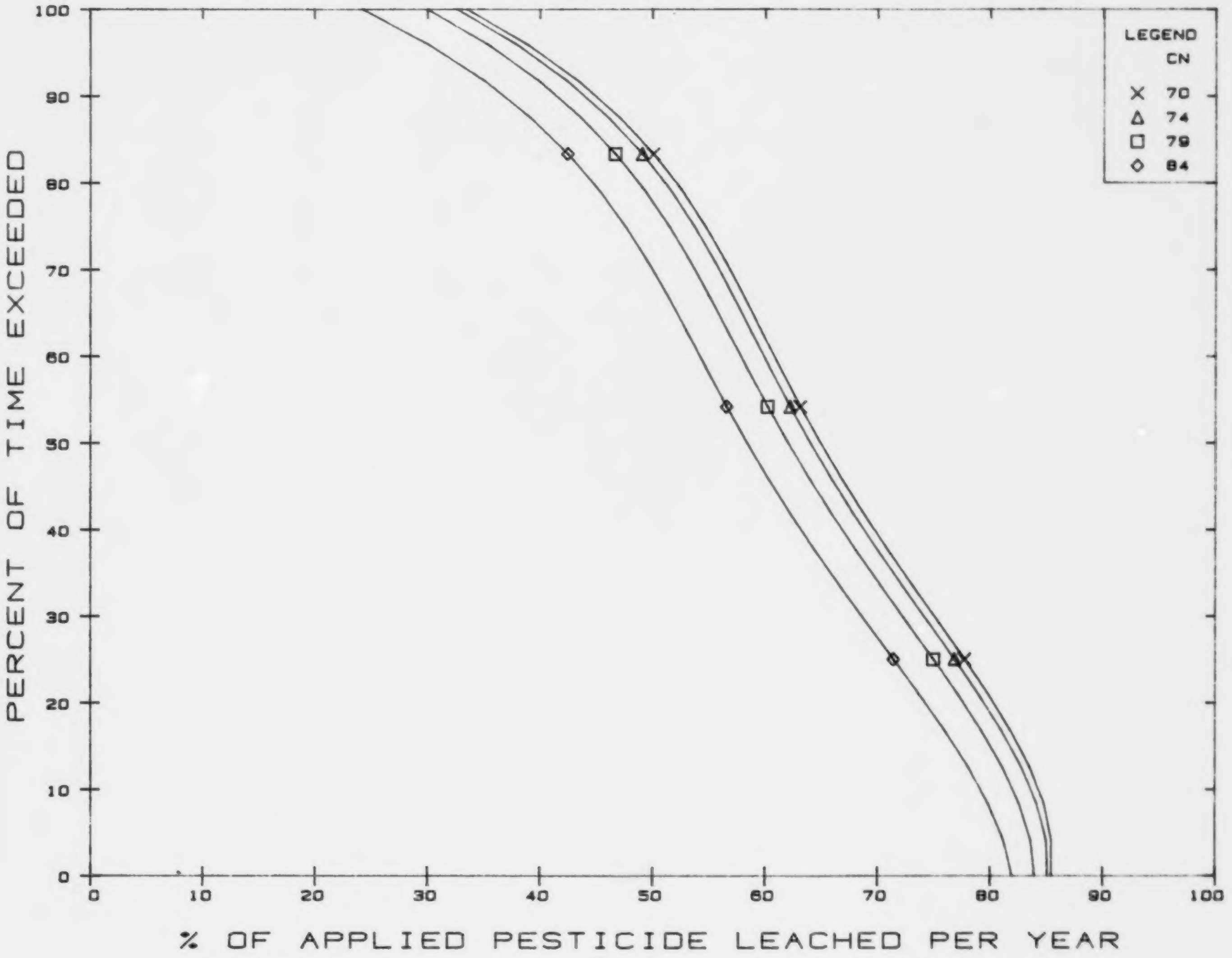


FIGURE A4-2 R=1. KS=.005

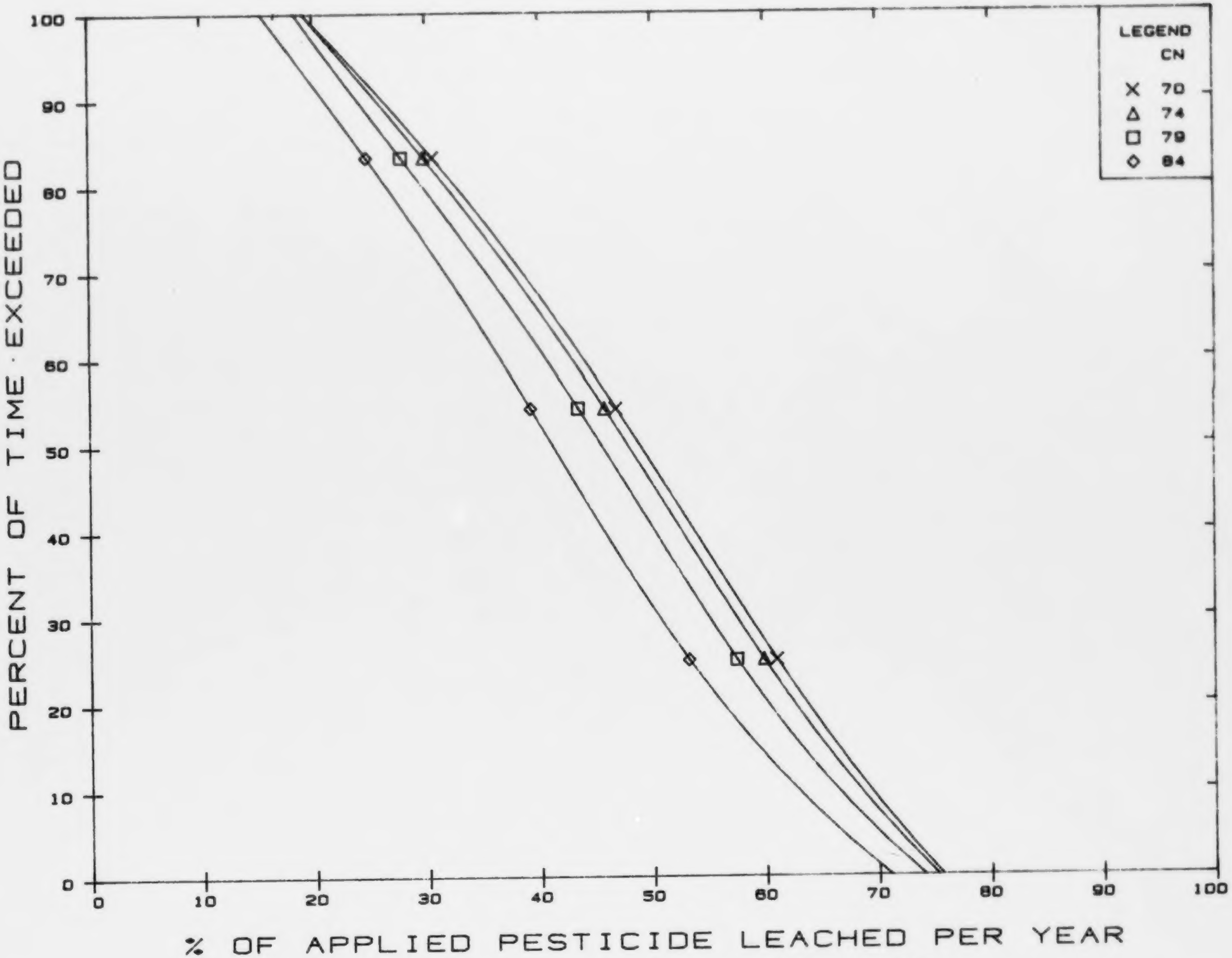


FIGURE A4-3 R=1. KS=.010

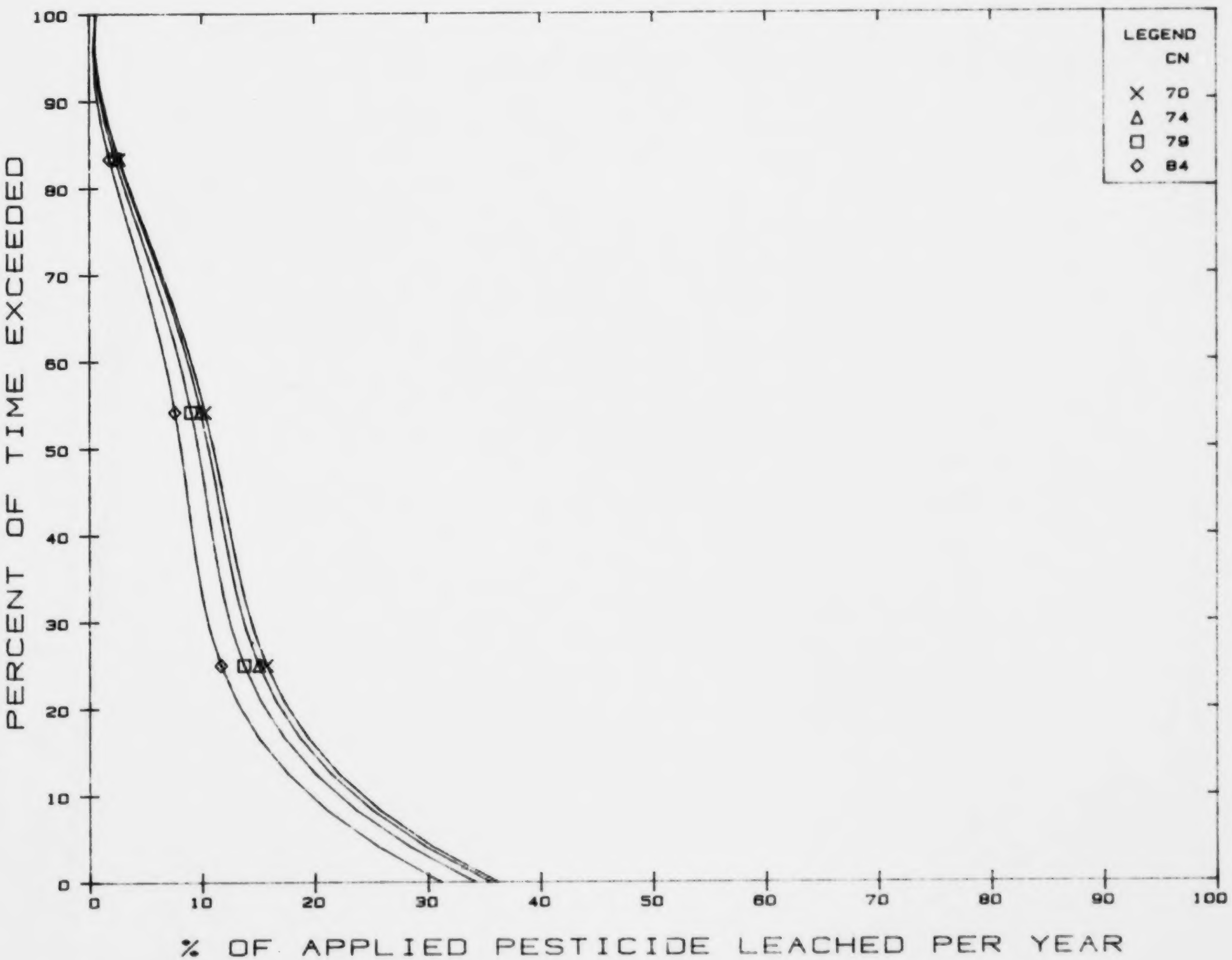


FIGURE A4-4 R=1. KS=.050

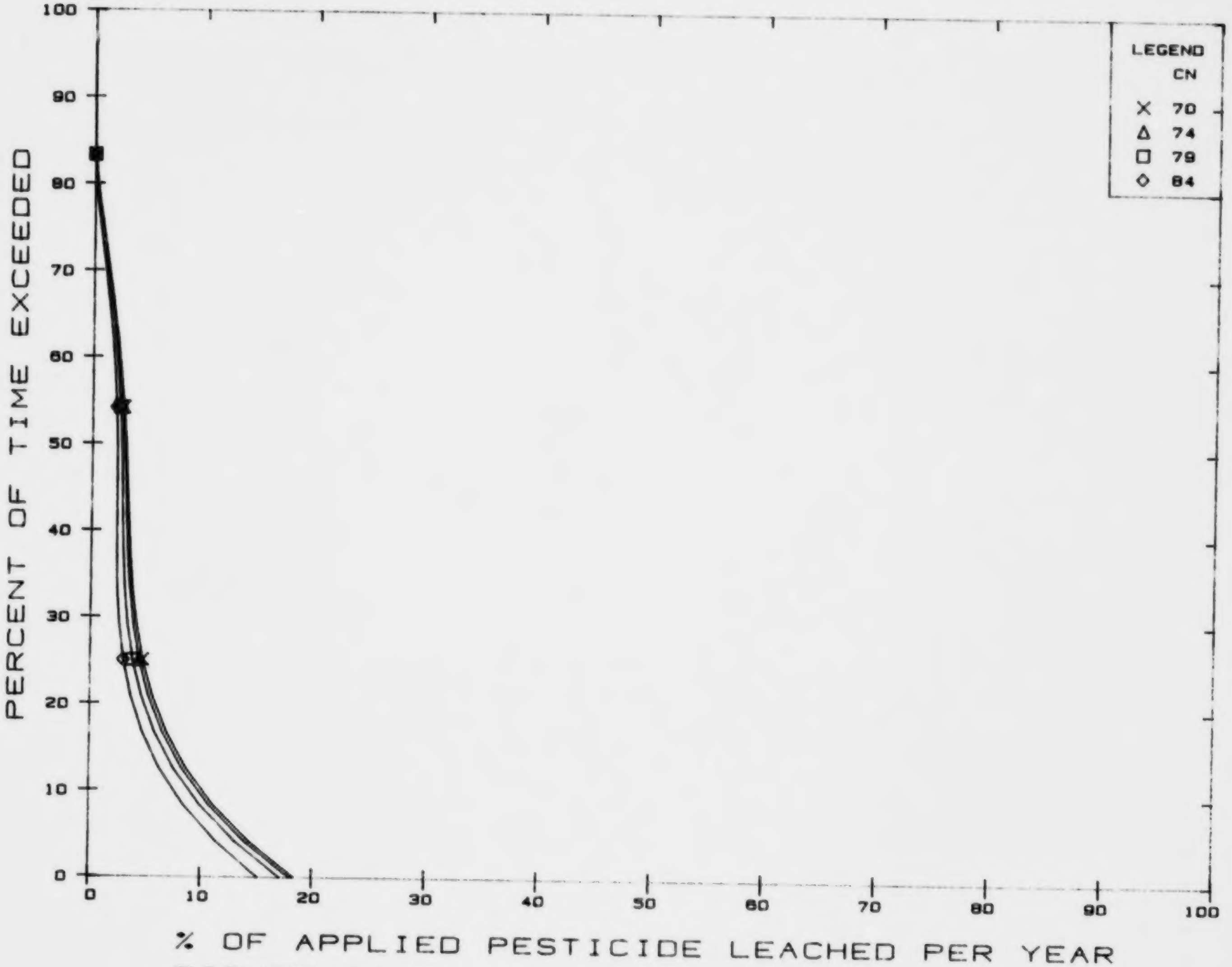


FIGURE A4-5 R=1. KS=.100

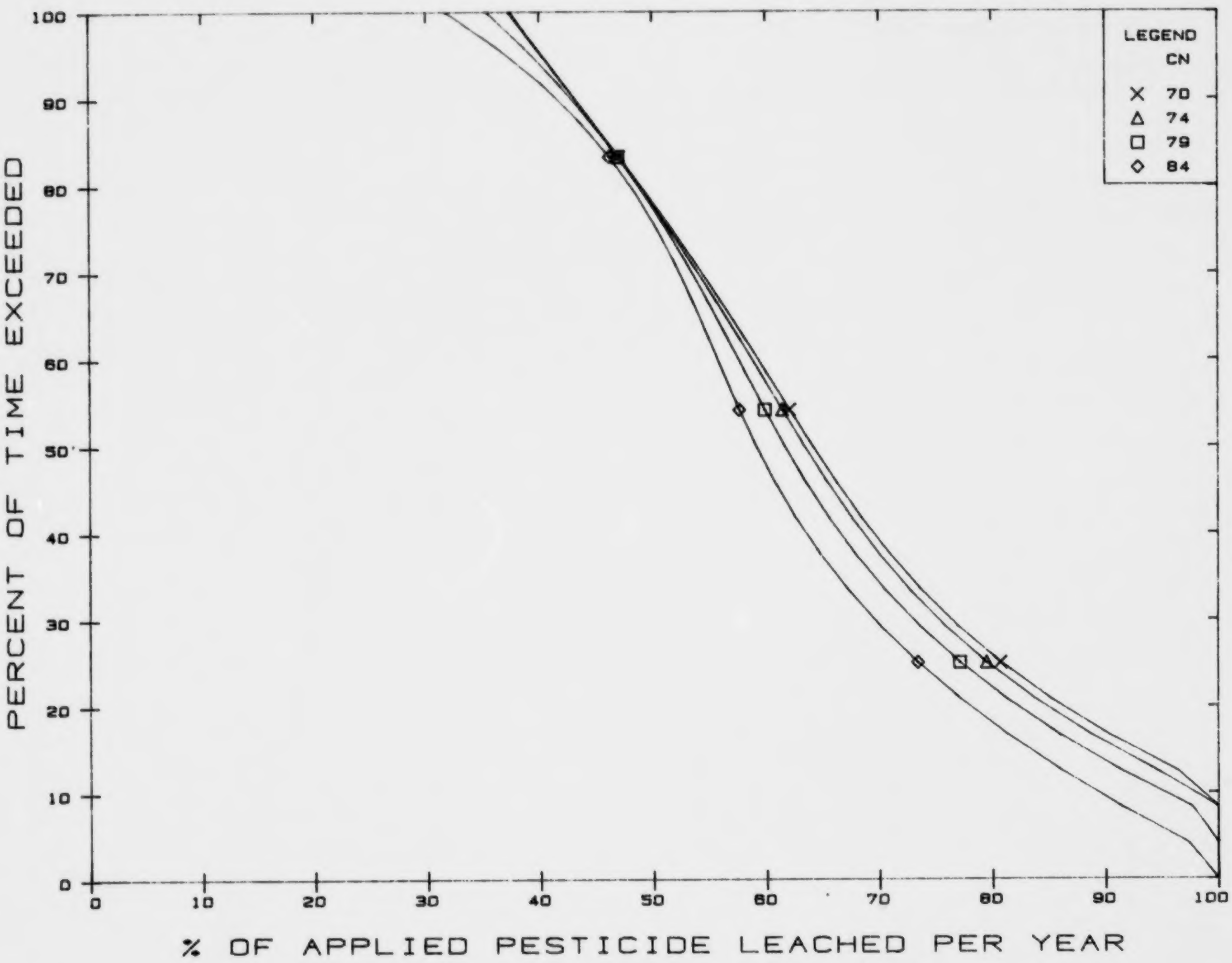


FIGURE A4-6 R=3. KS=.001

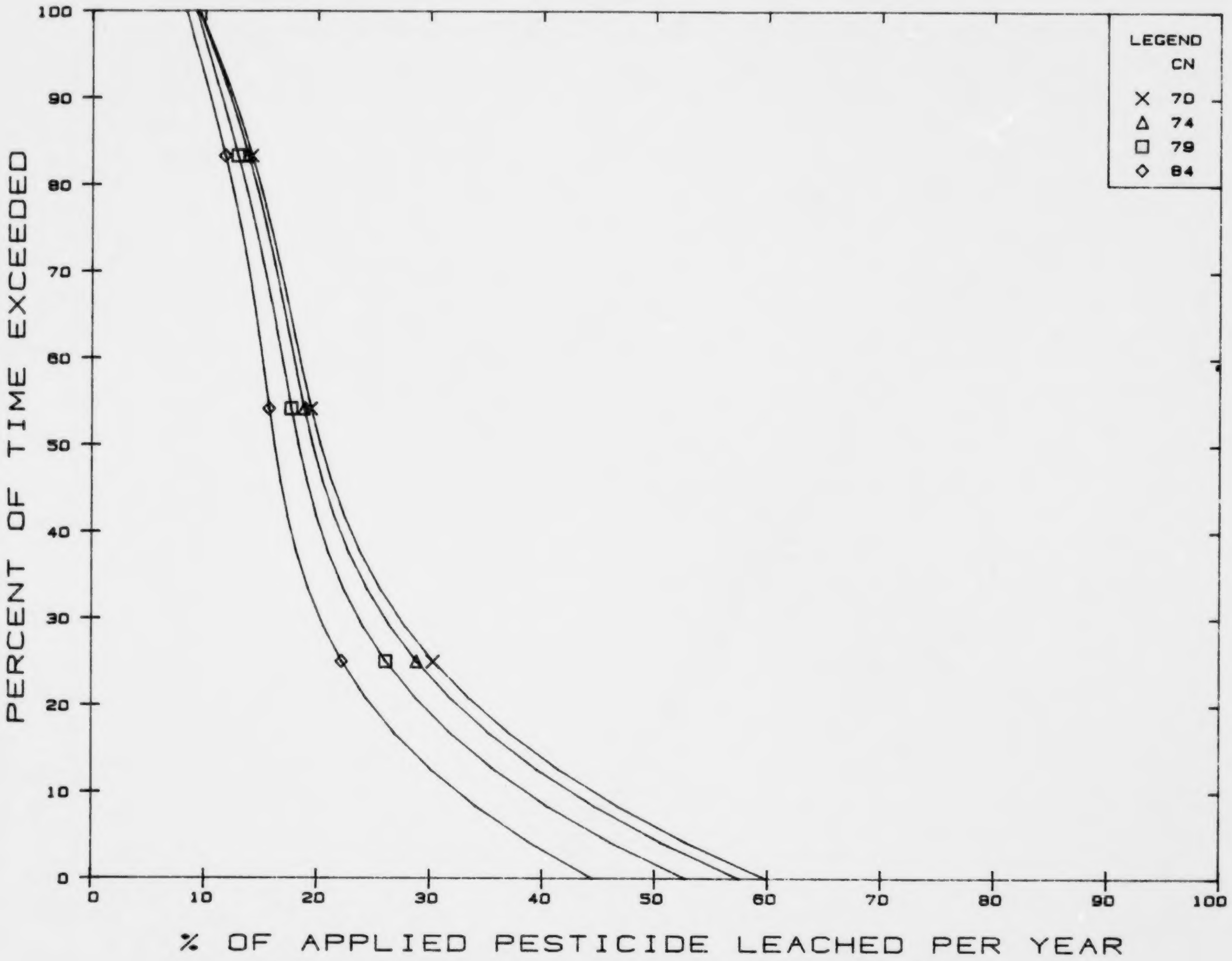


FIGURE A4-7 R=3. KS=.005

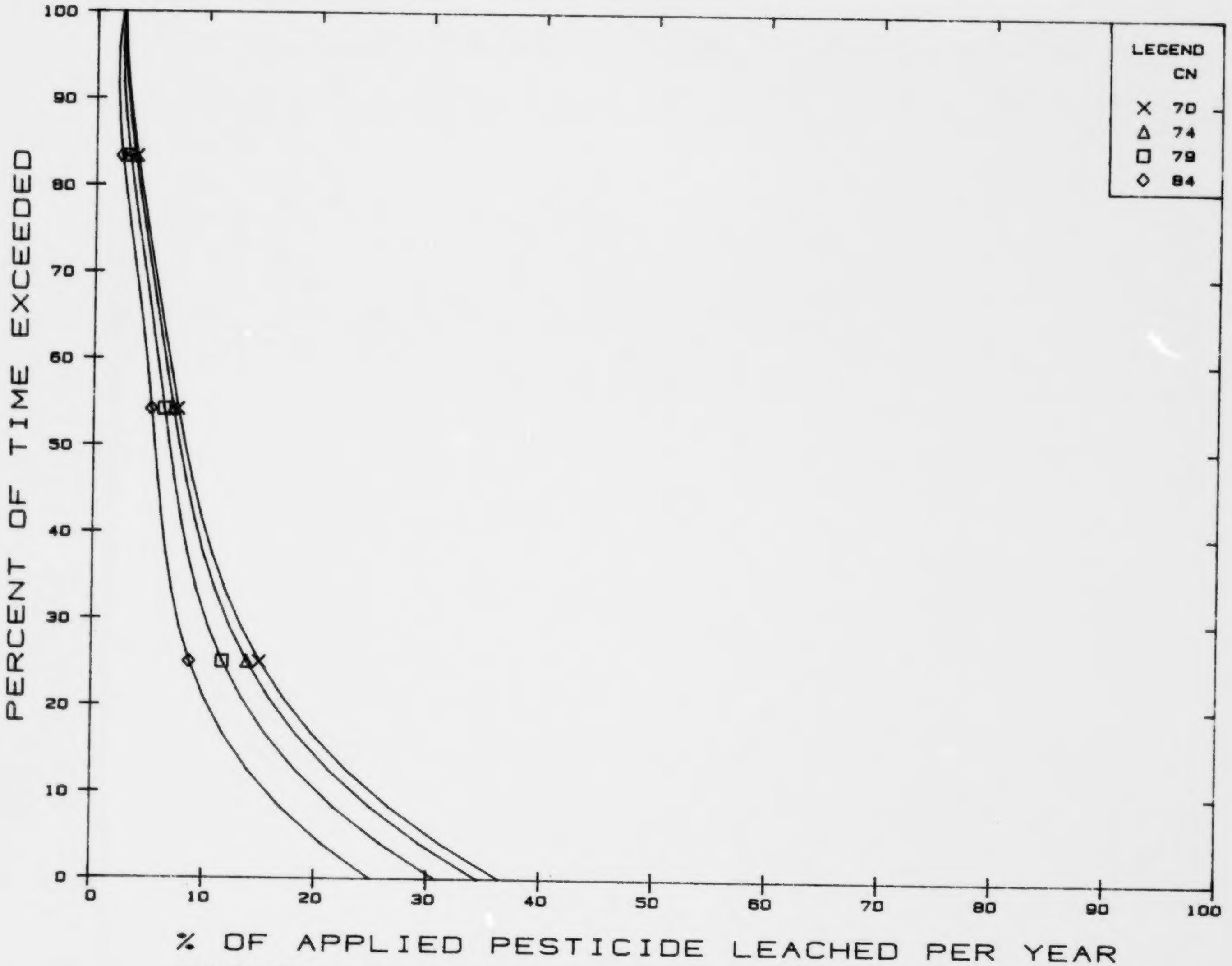
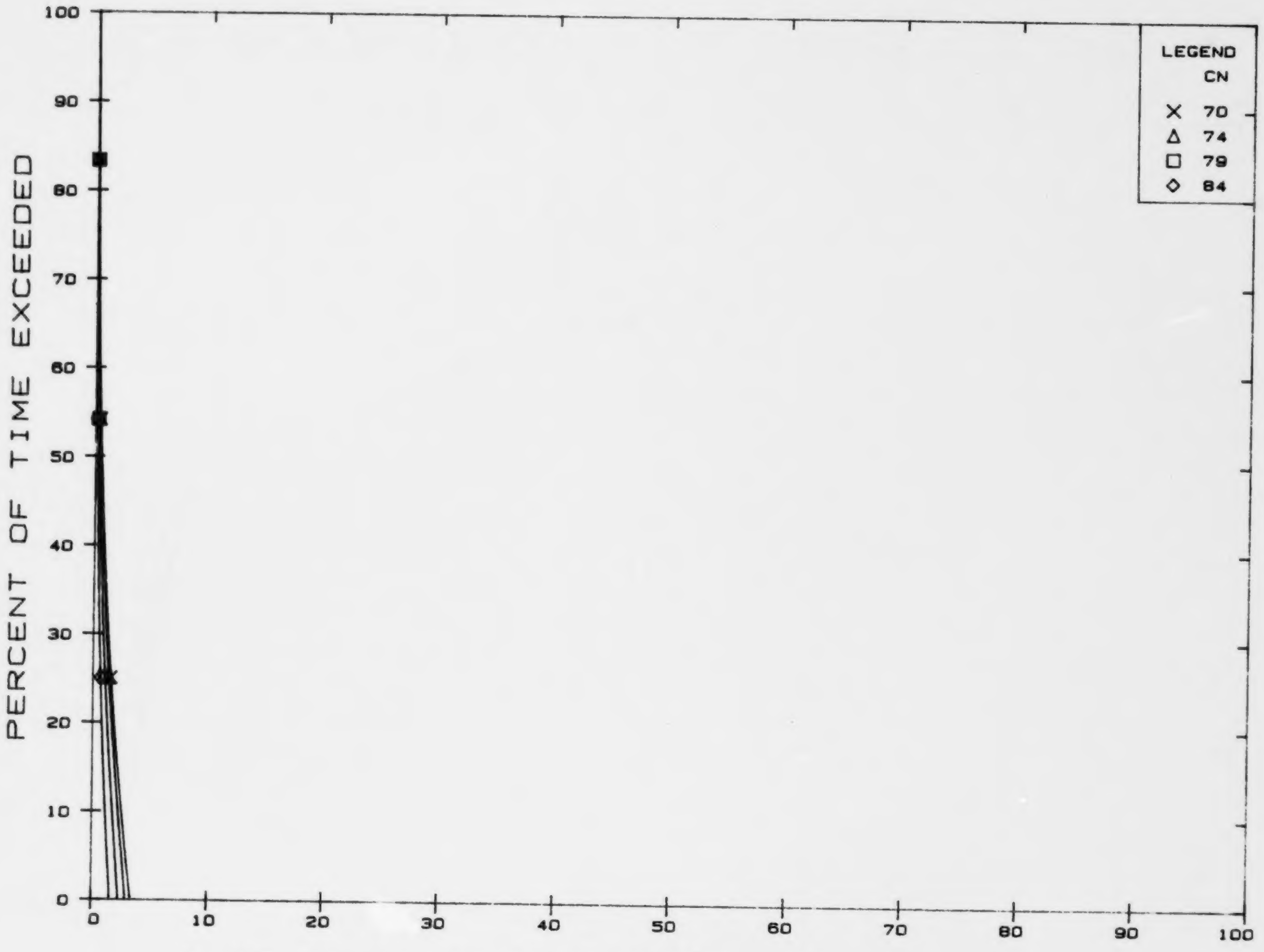


FIGURE A4-8 R=3. KS=.010



% OF APPLIED PESTICIDE LEACHED PER YEAR
FIGURE A4-9 R=3. KS=.050

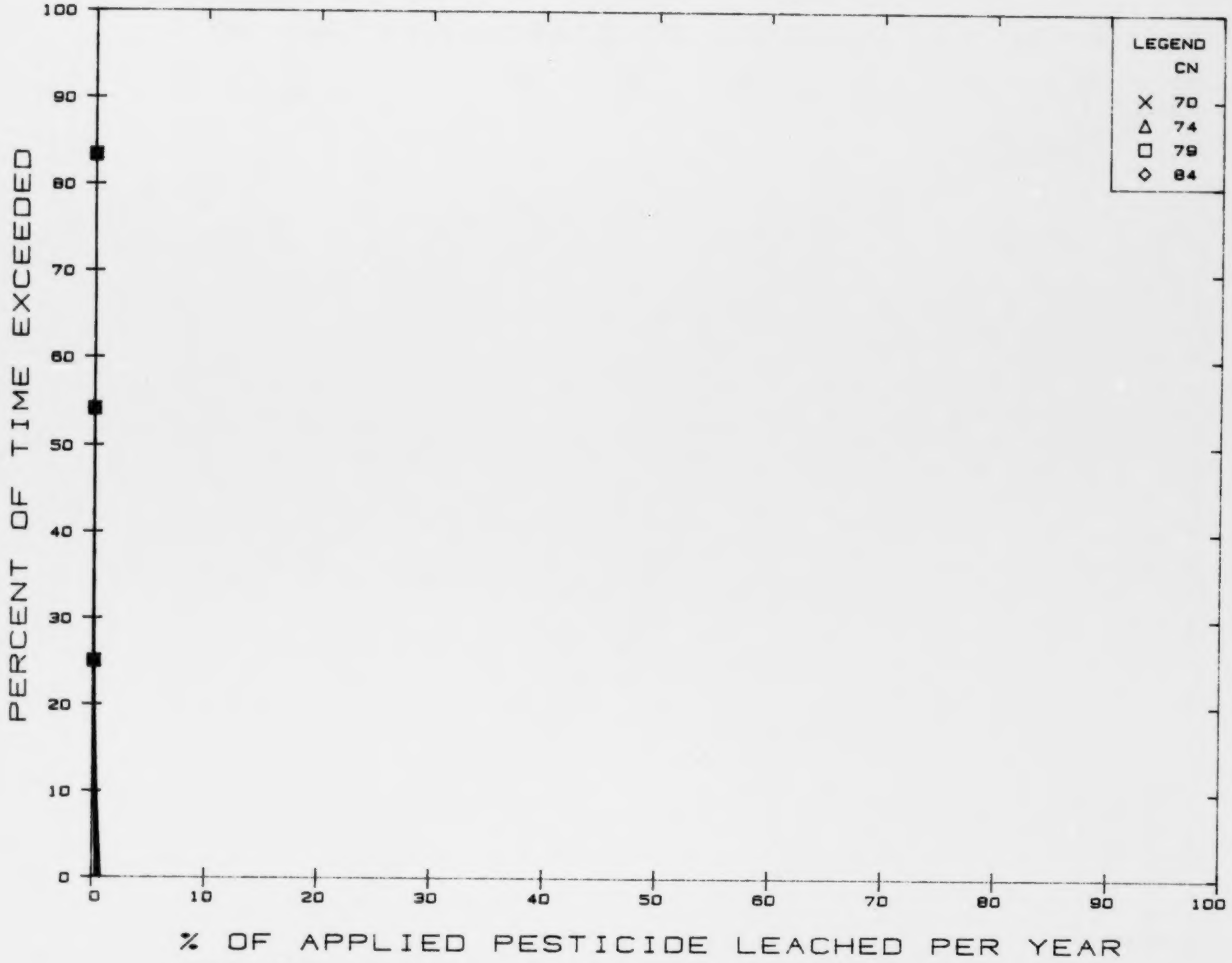


FIGURE A4-10 R=3. KS=.100

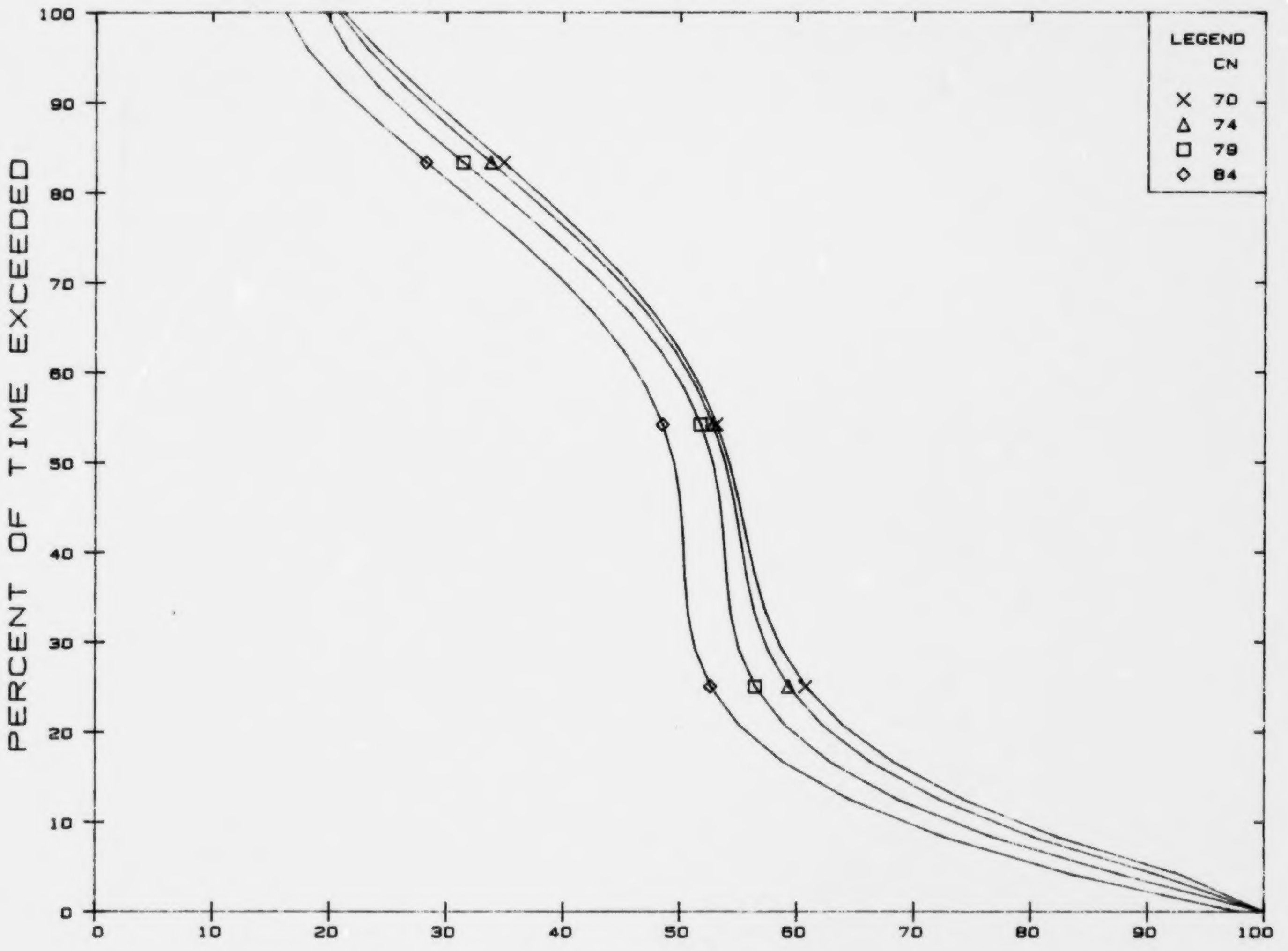


FIGURE A4-11 R=5. KS=.001

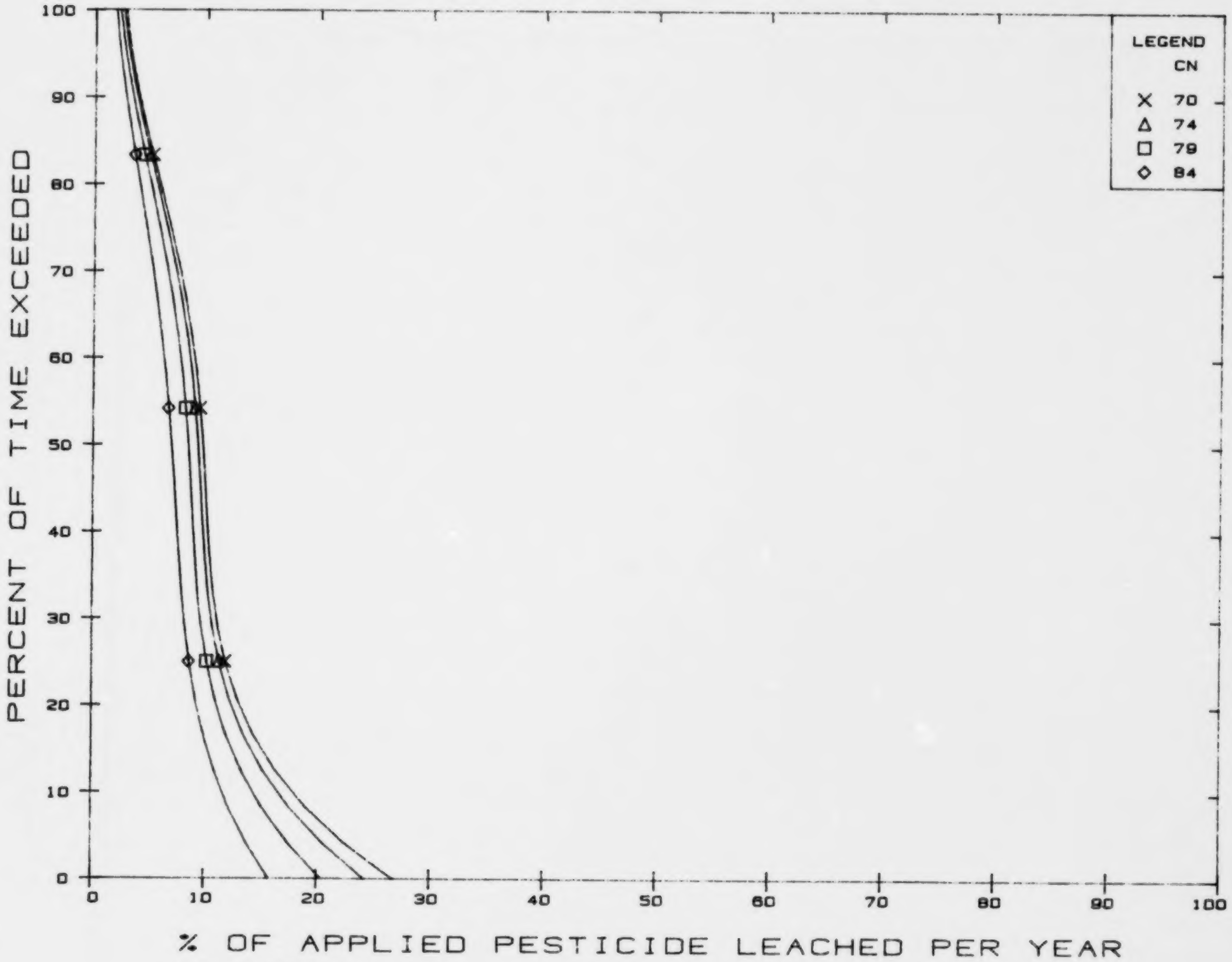


FIGURE A4-12 R=5. KS=.005

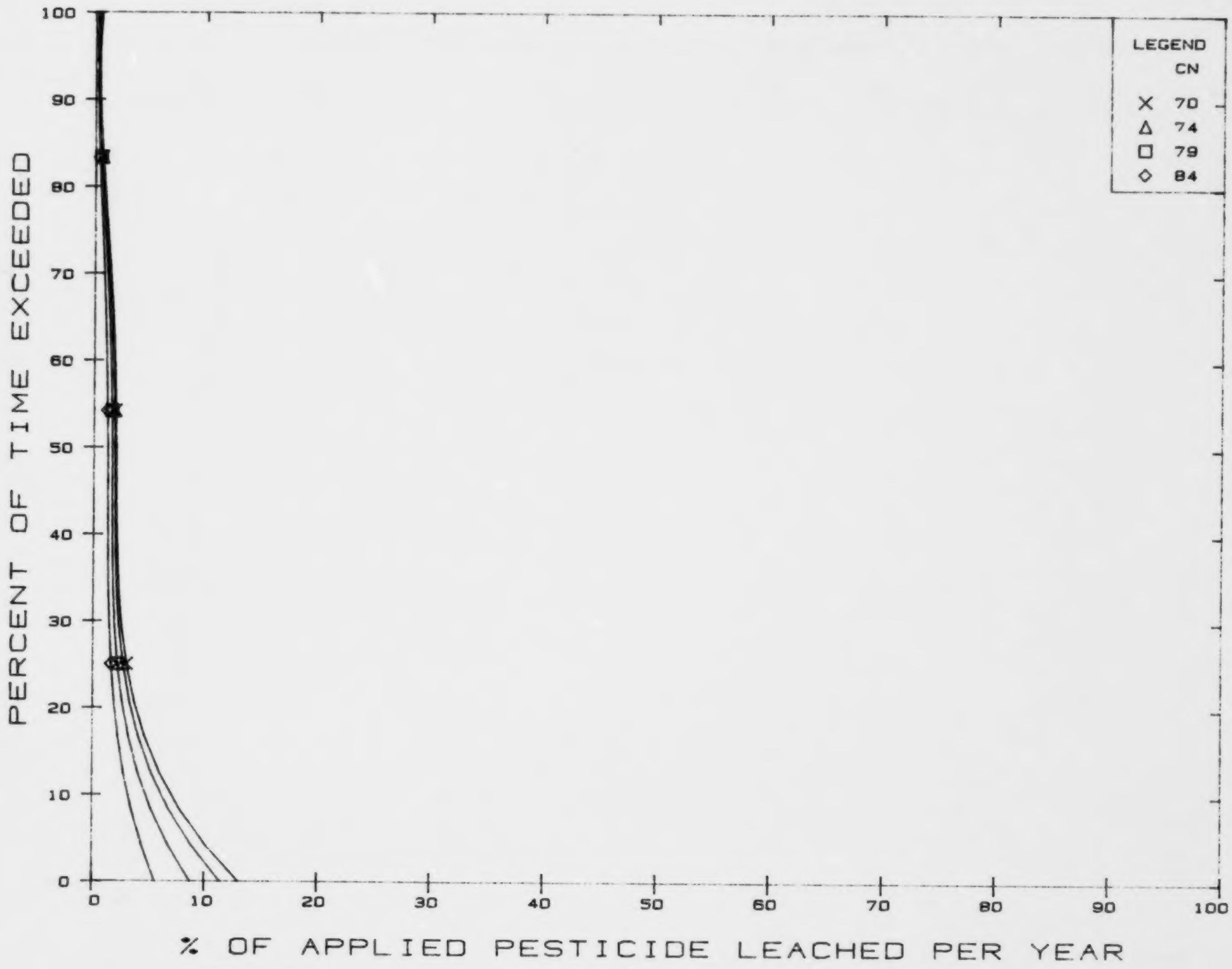


FIGURE A4-13 R=5. KS=.010

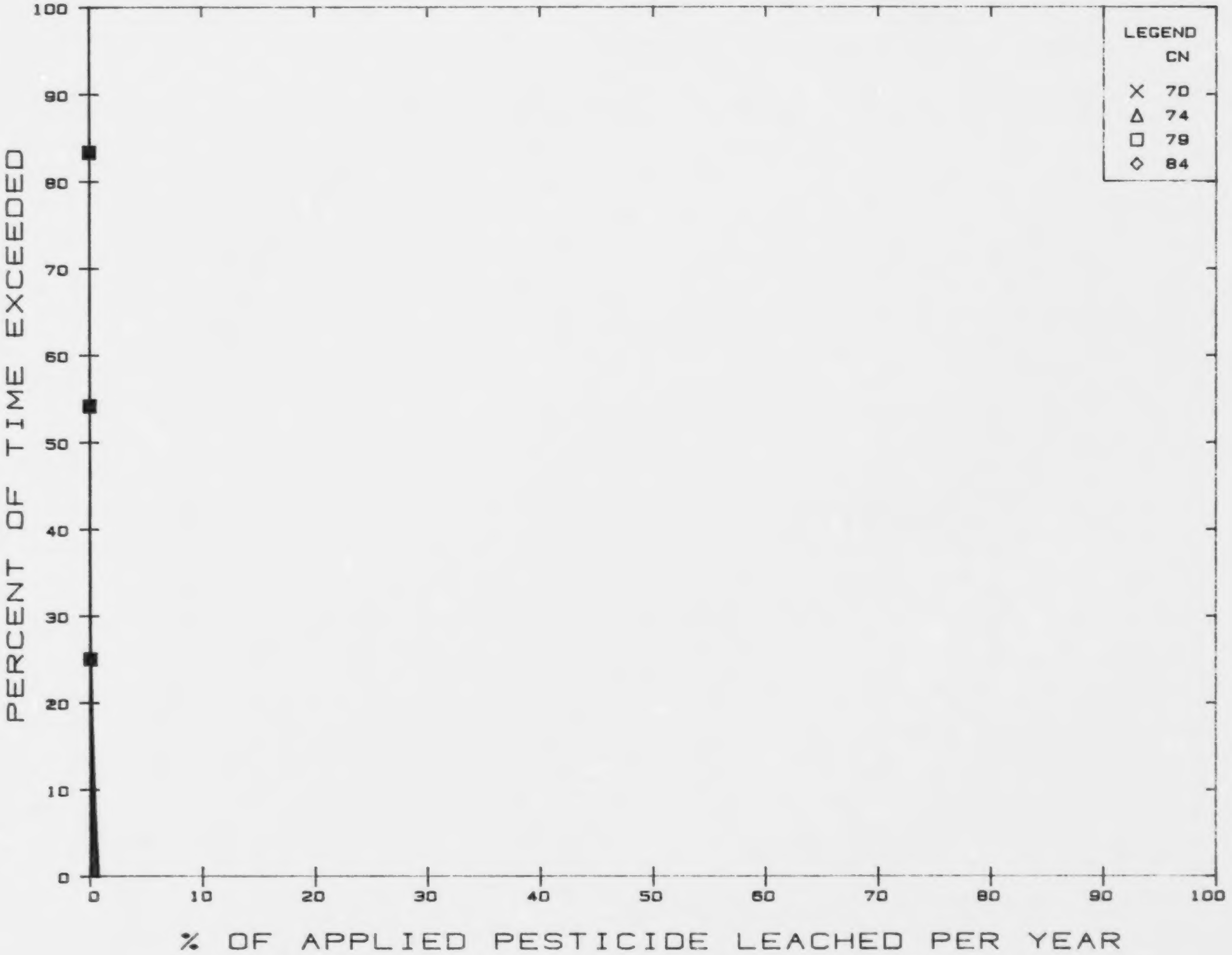


FIGURE A4-14 R=5. KS=.050

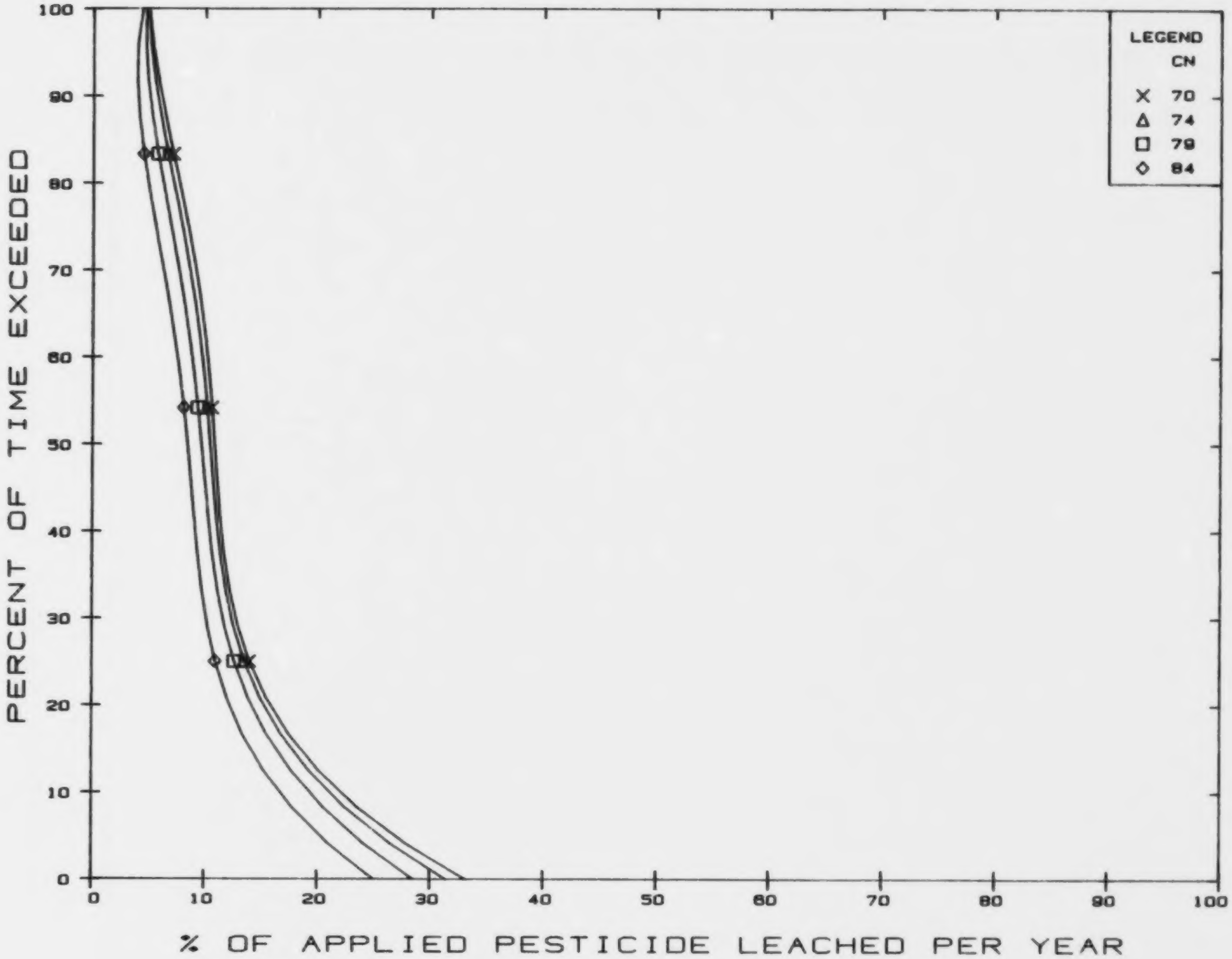


FIGURE A4-15 R=20. KS=.001

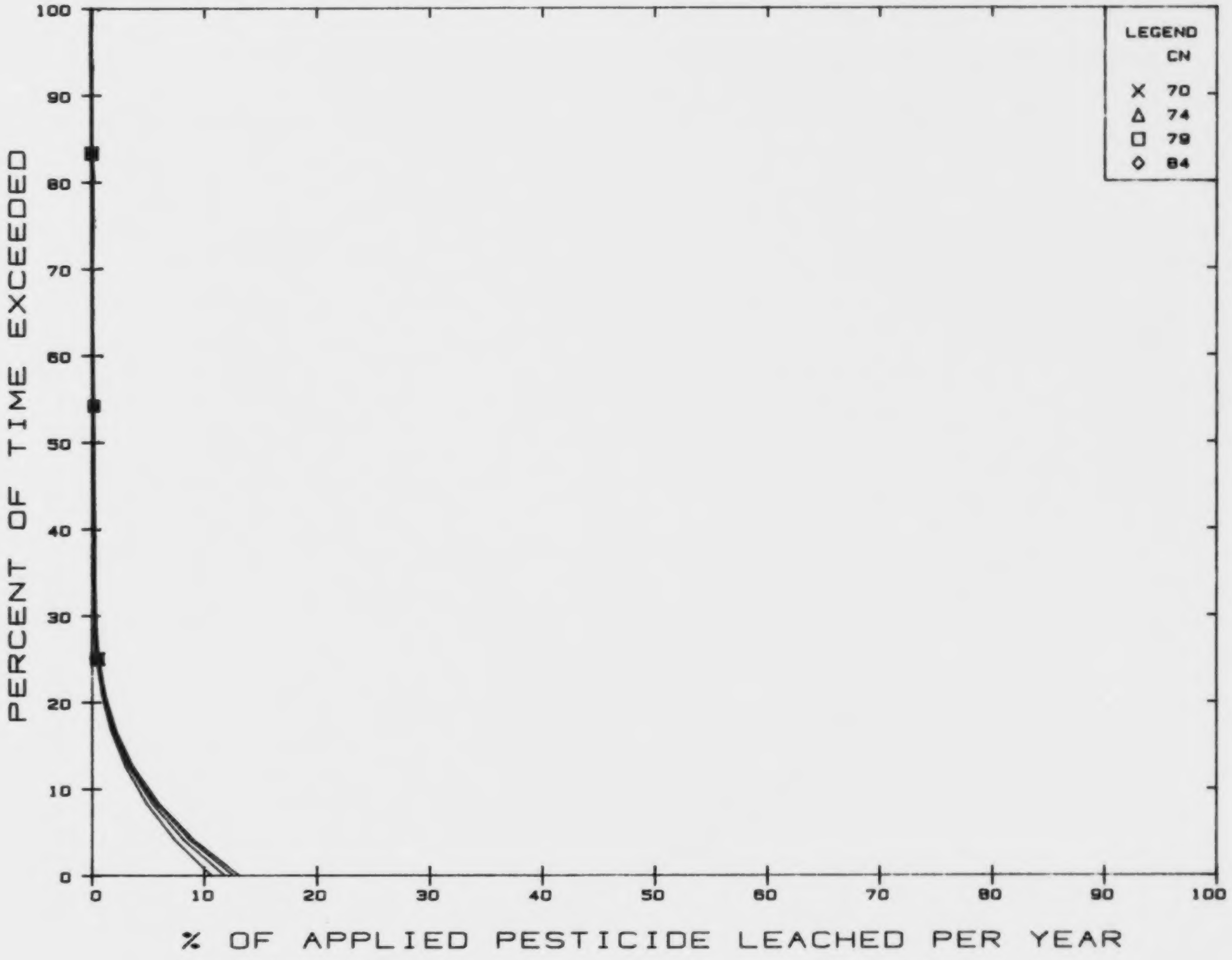


FIGURE A4-16 R=50. KS=.001

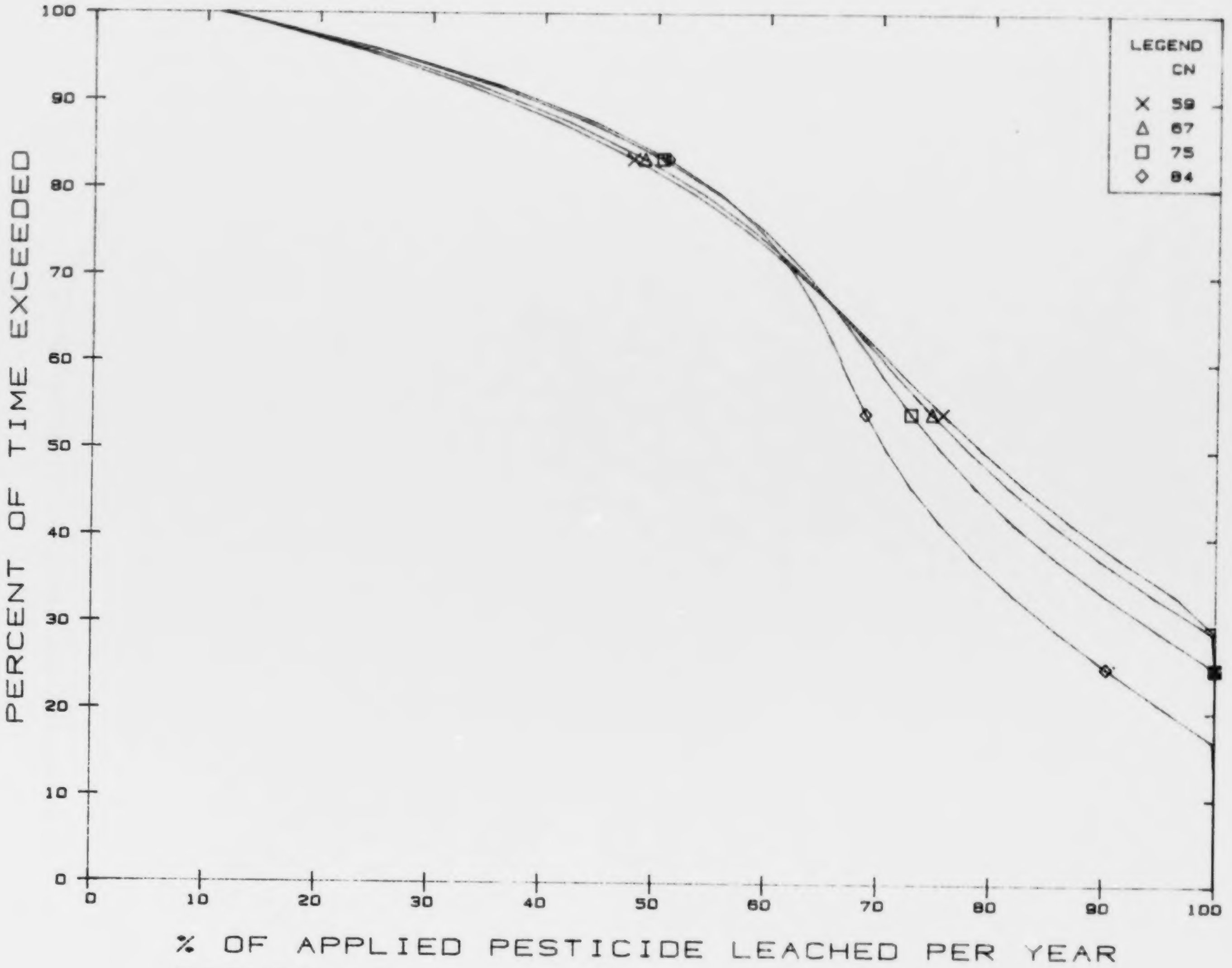


FIGURE A5-1 R=1. KS=.001

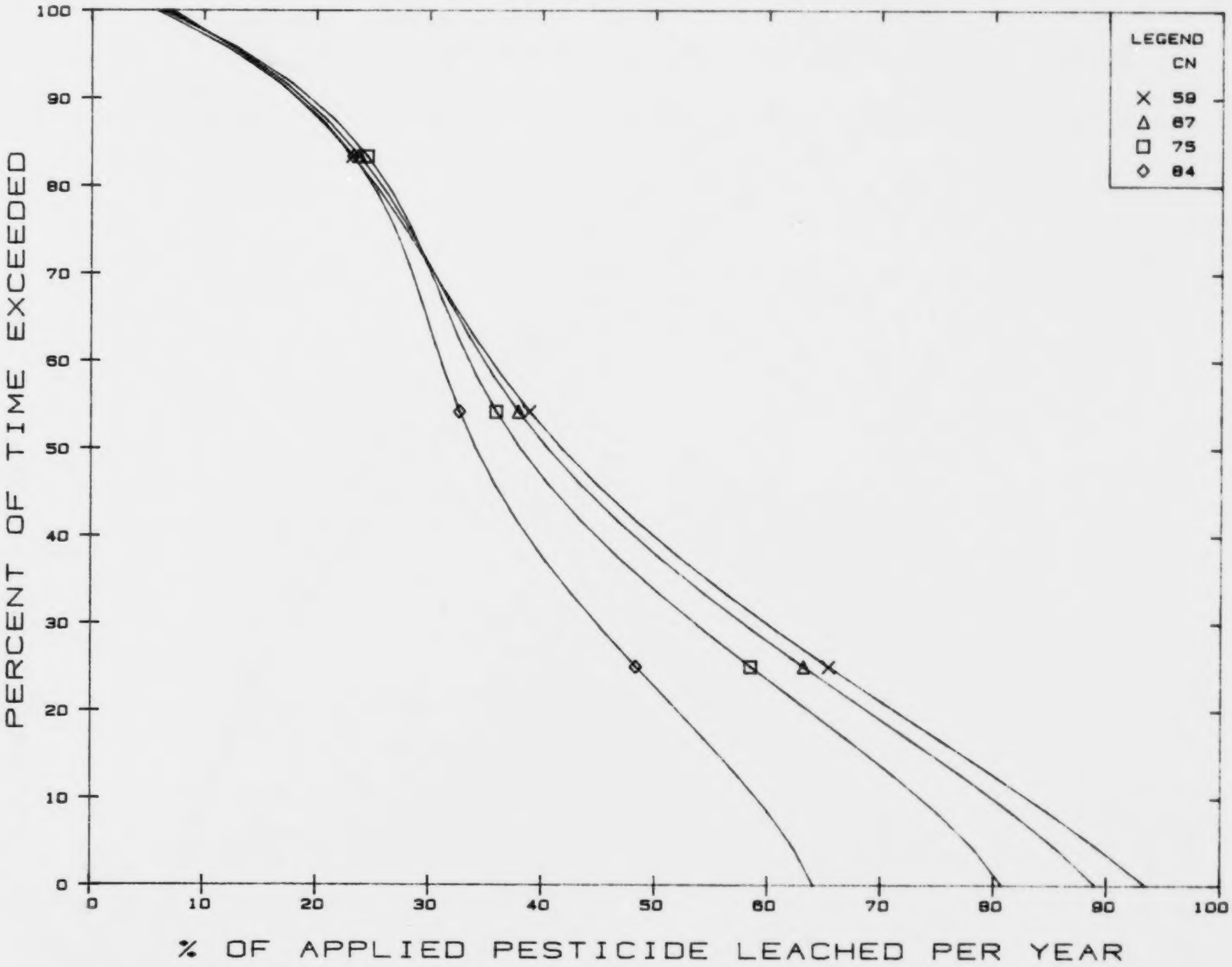


FIGURE A5-2 R=1. KS=.005

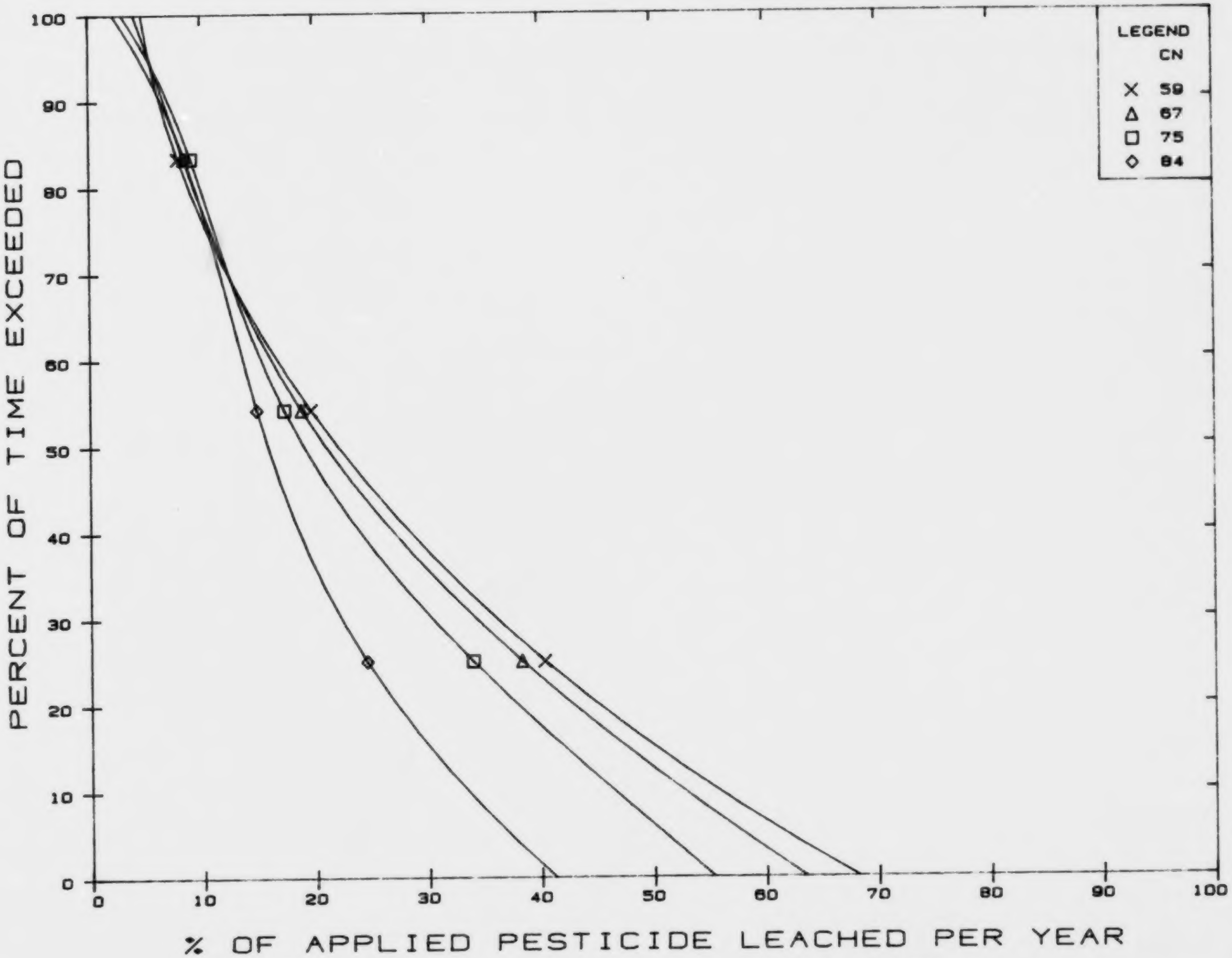


FIGURE A5-3 R=1. KS=.010

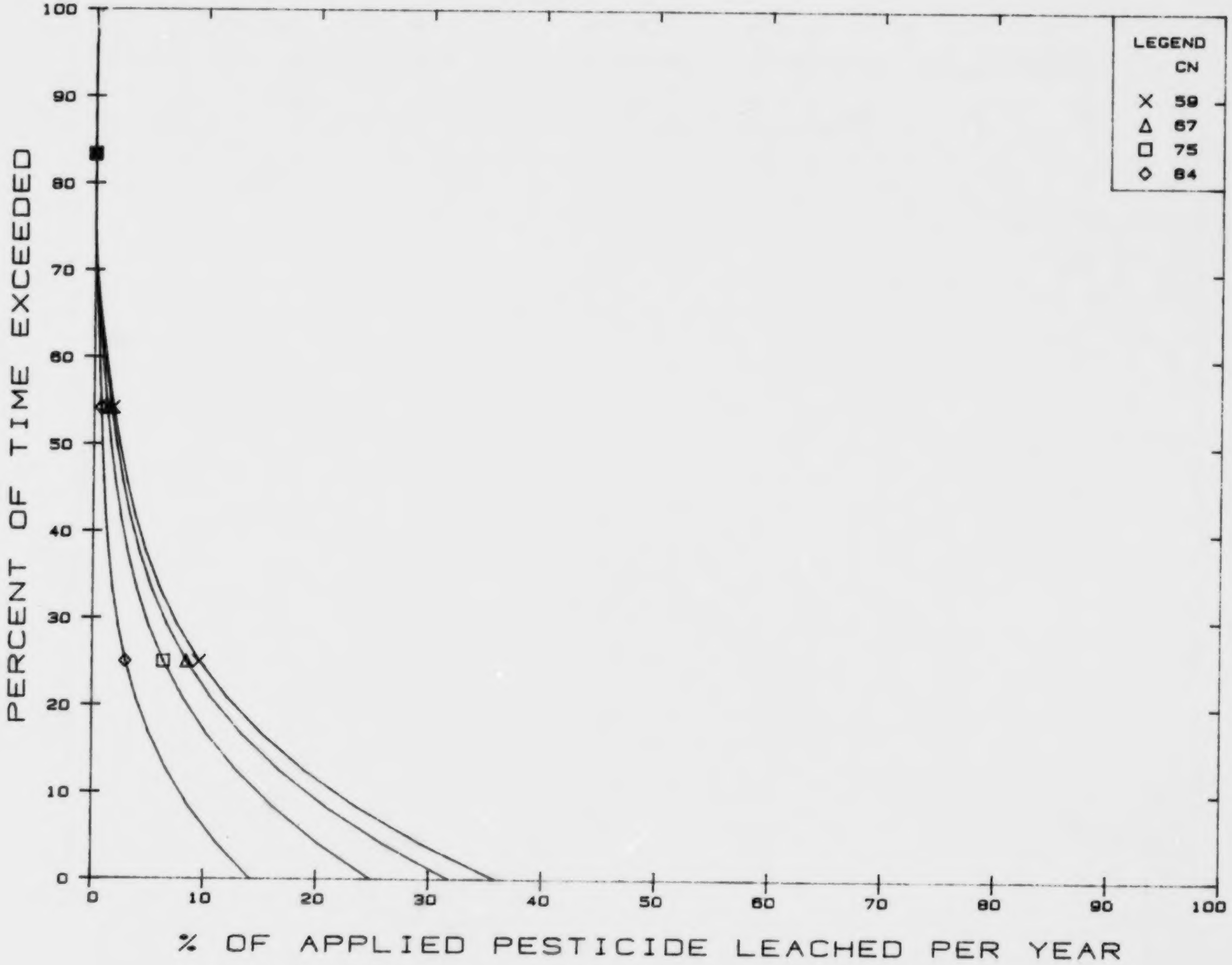


FIGURE A5-4 R=1. KS=.050

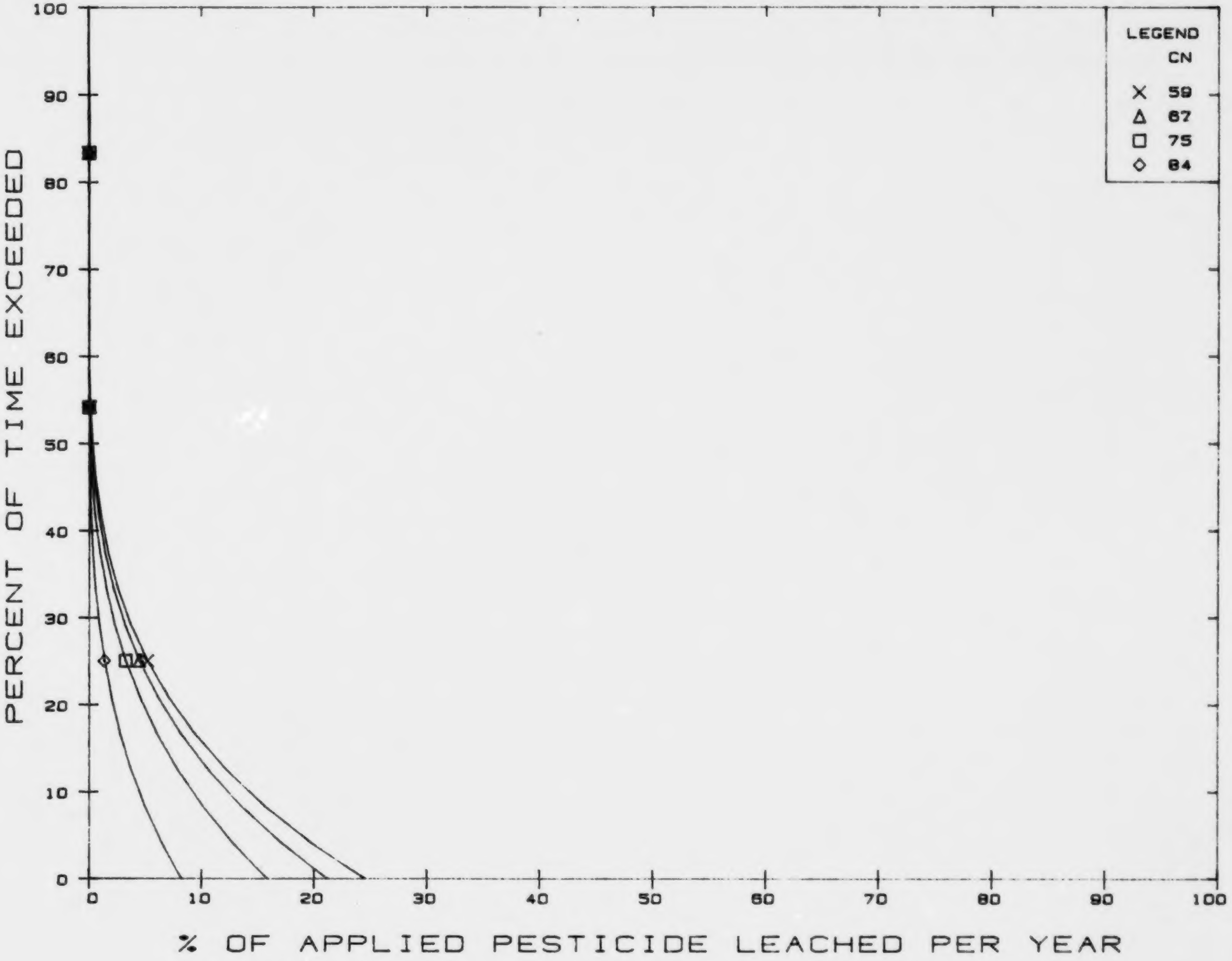


FIGURE A5-5 R=1. KS=.100

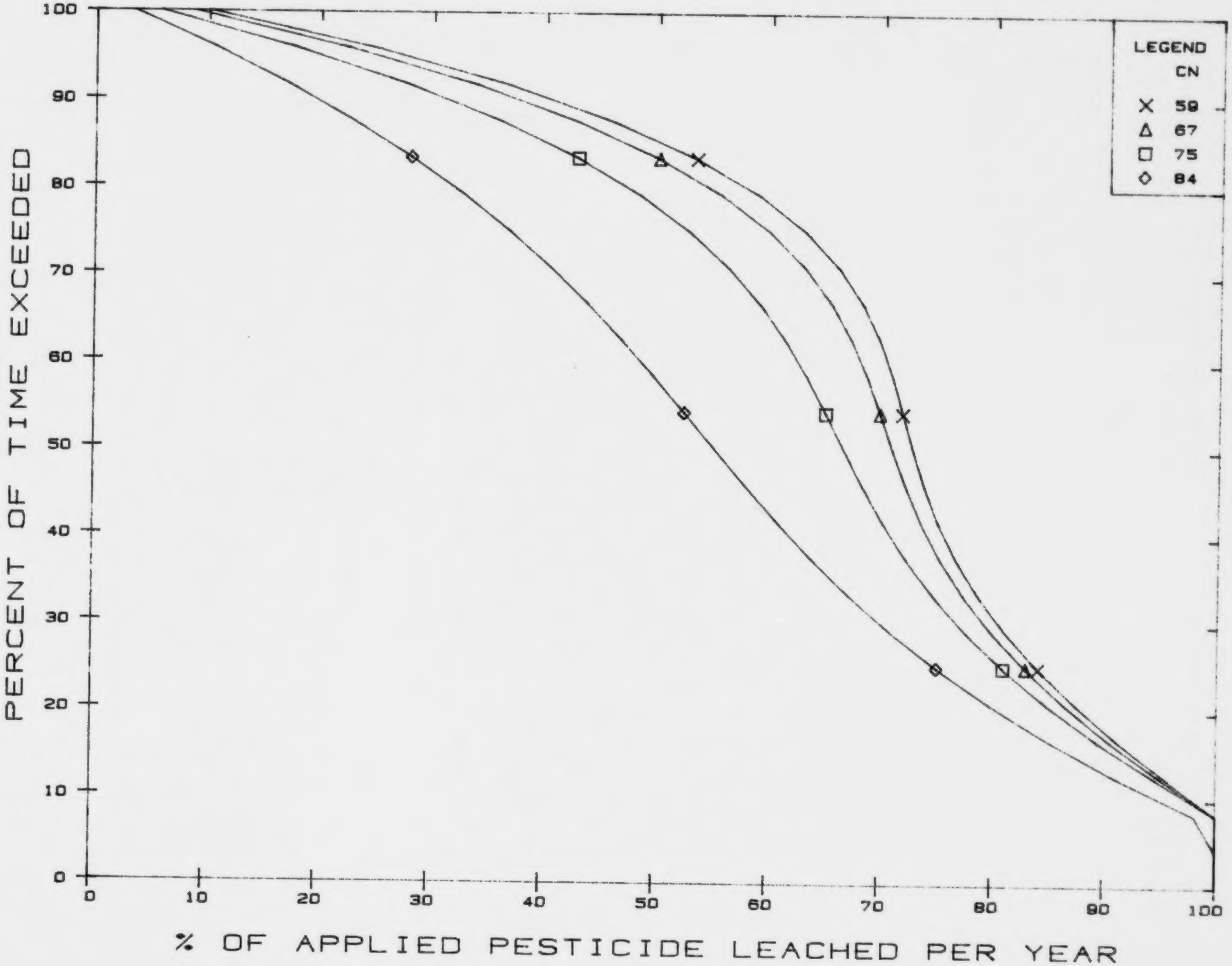


FIGURE A5-6 R=3. KS=.001

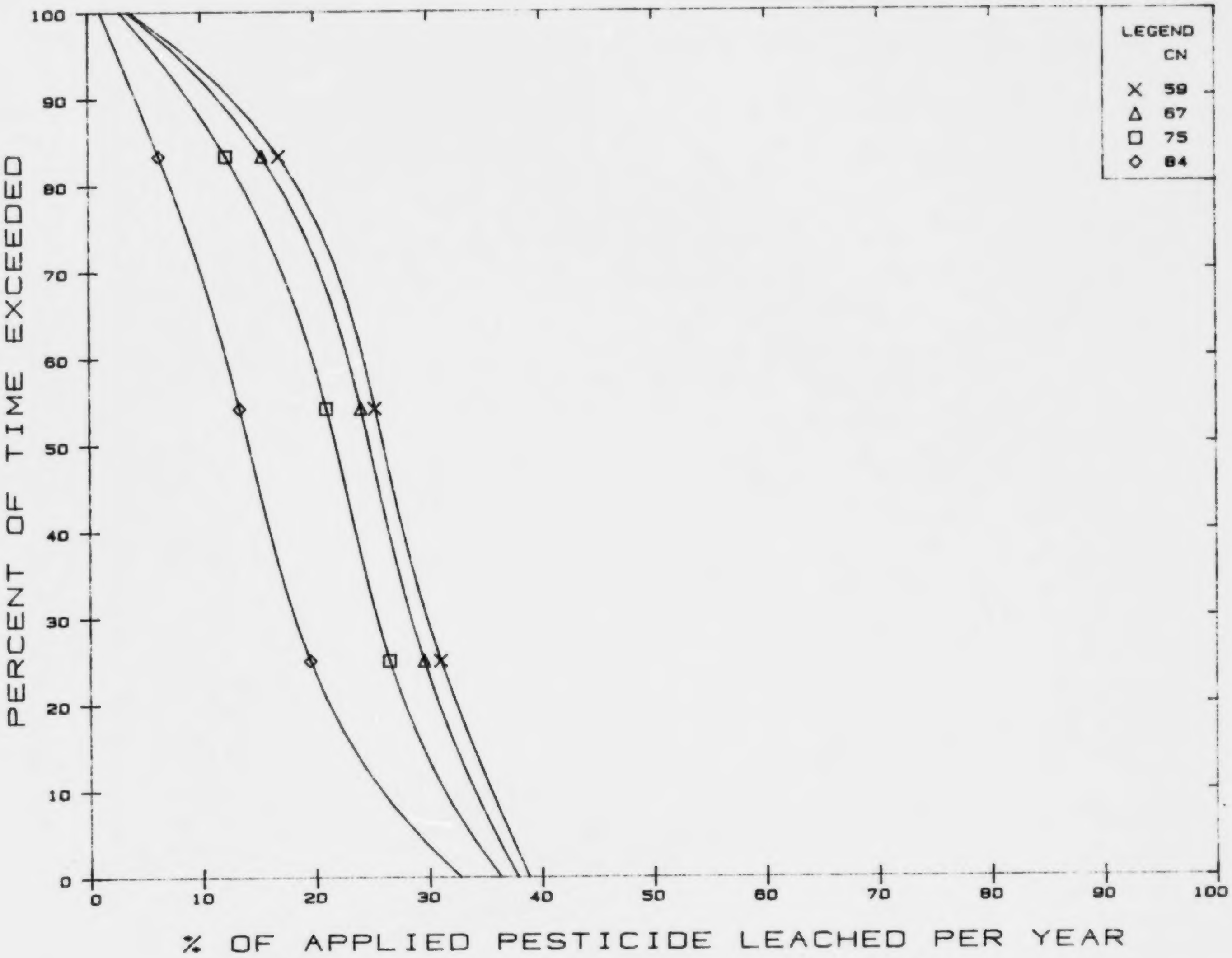


FIGURE A5-7 R=3. KS=.005

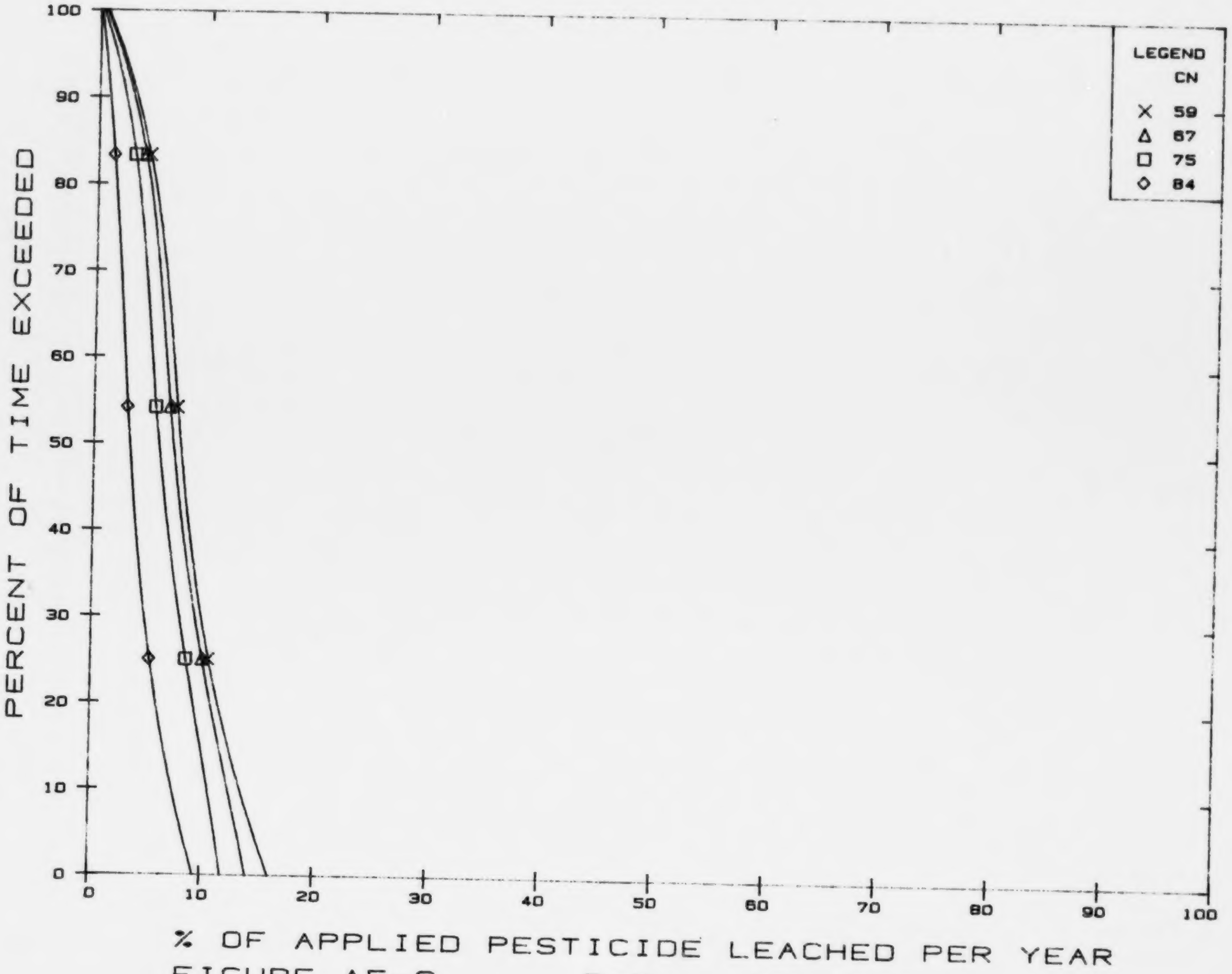


FIGURE A5-8 R=3. KS=.010

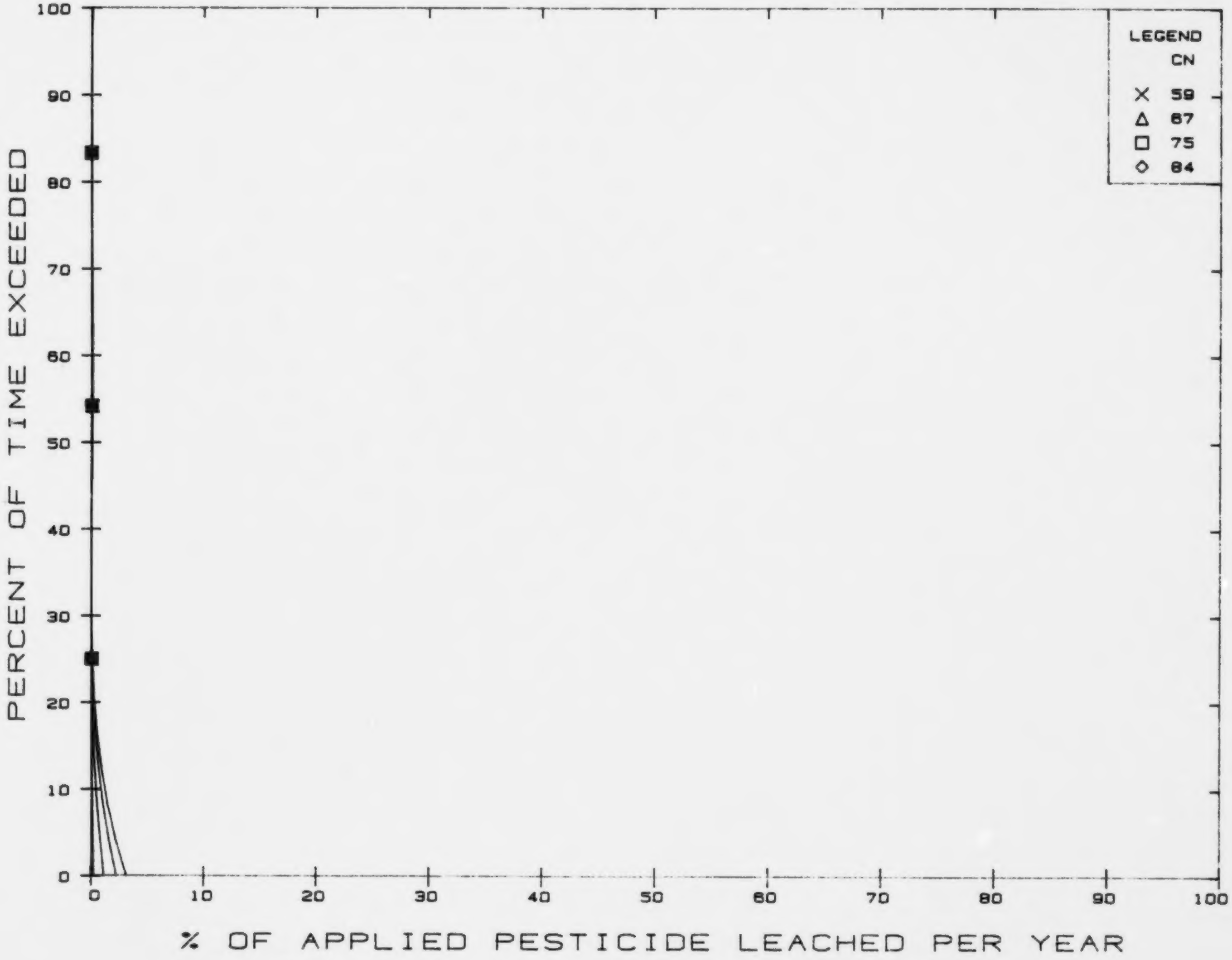


FIGURE A5-9 R=3. KS=.050

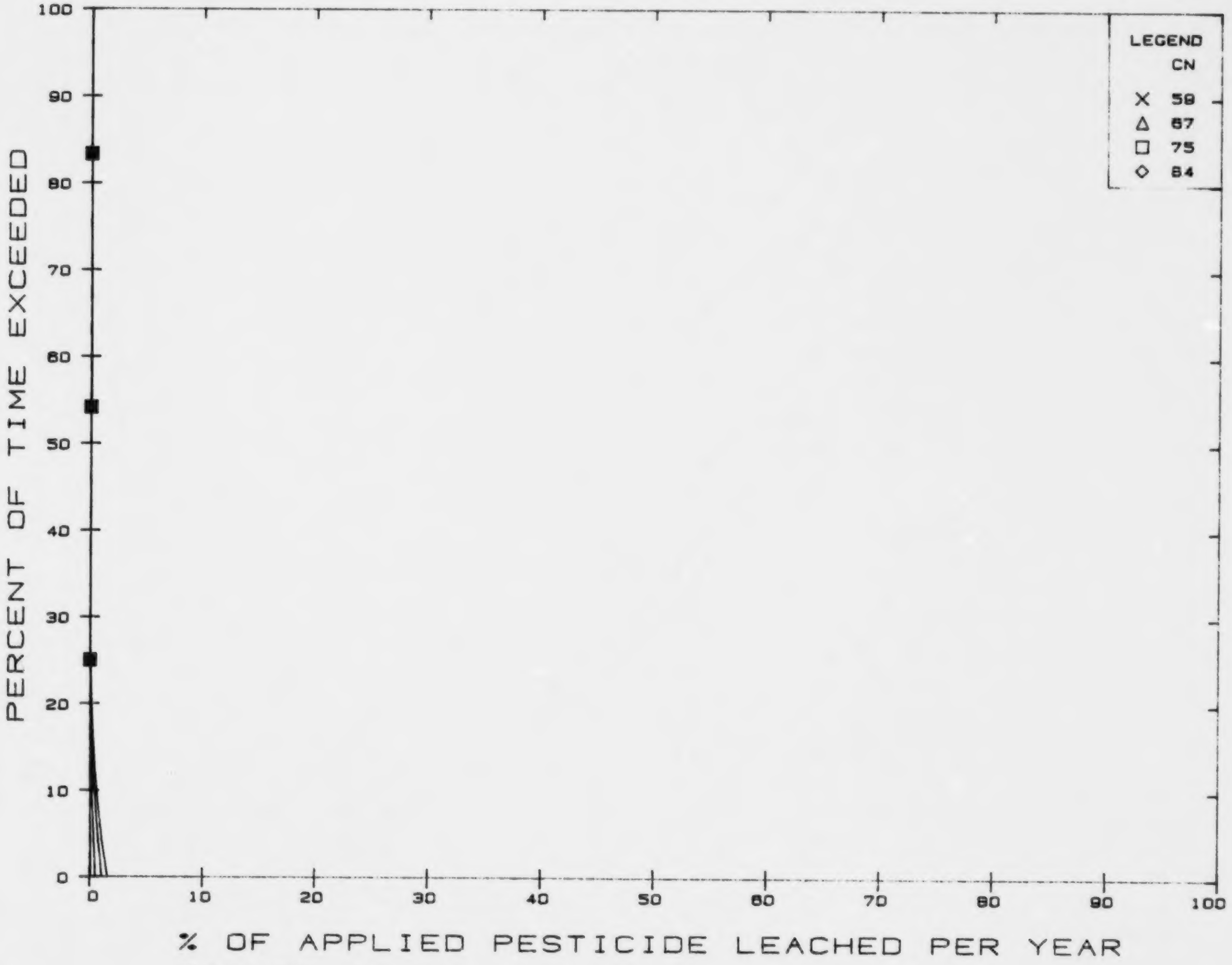


FIGURE A5-10 R=3. KS=.100

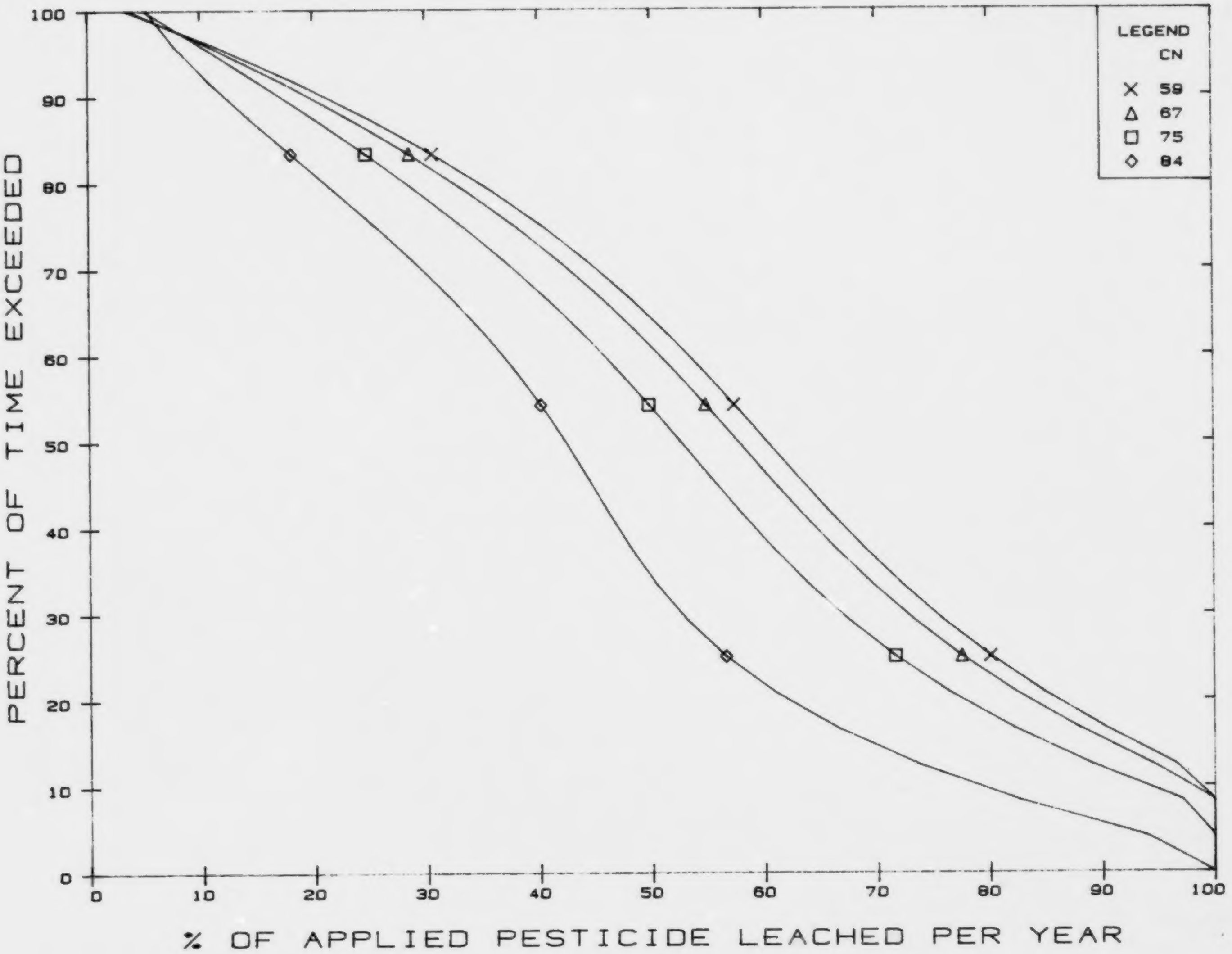


FIGURE A5-11 R=5. KS=.001

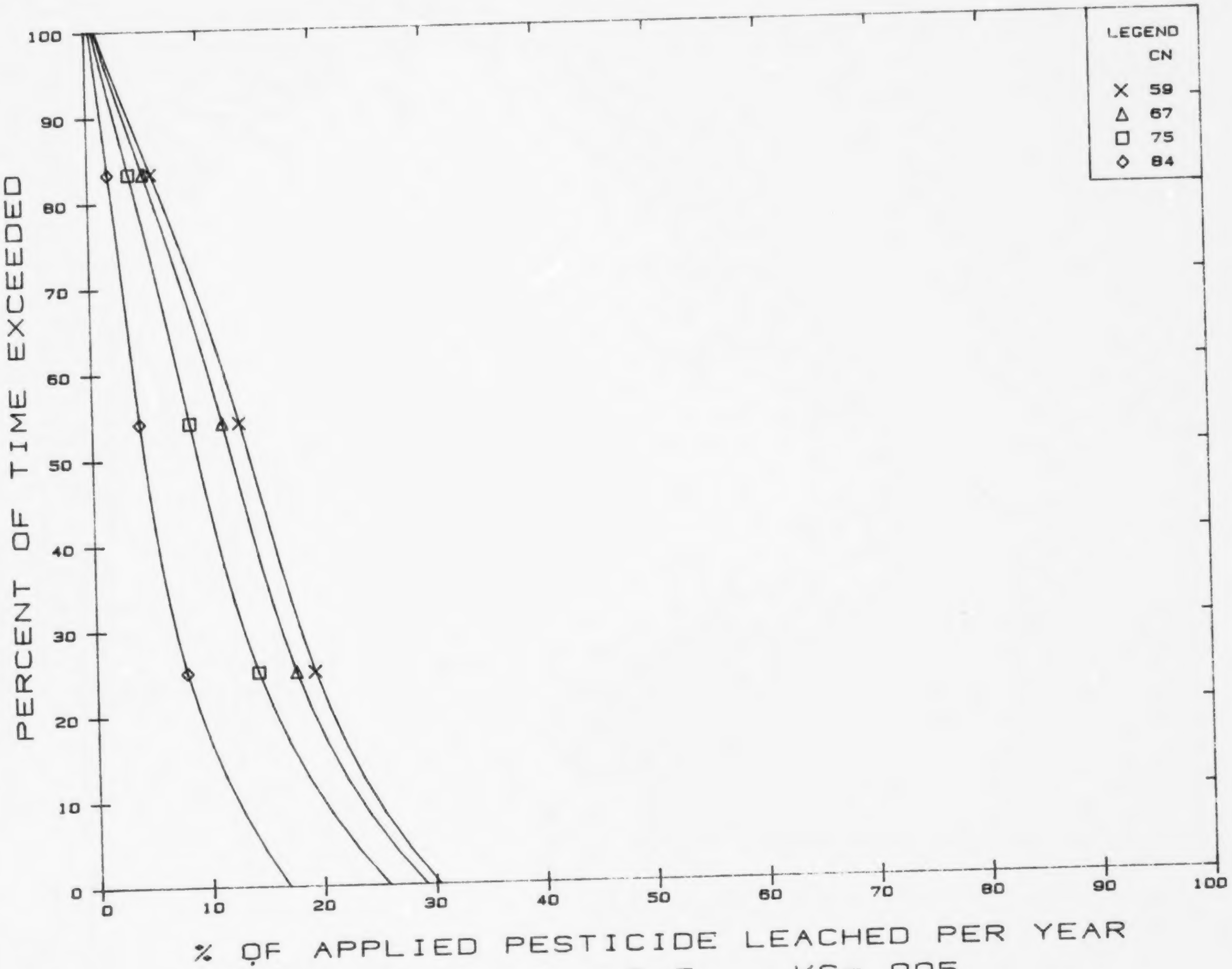
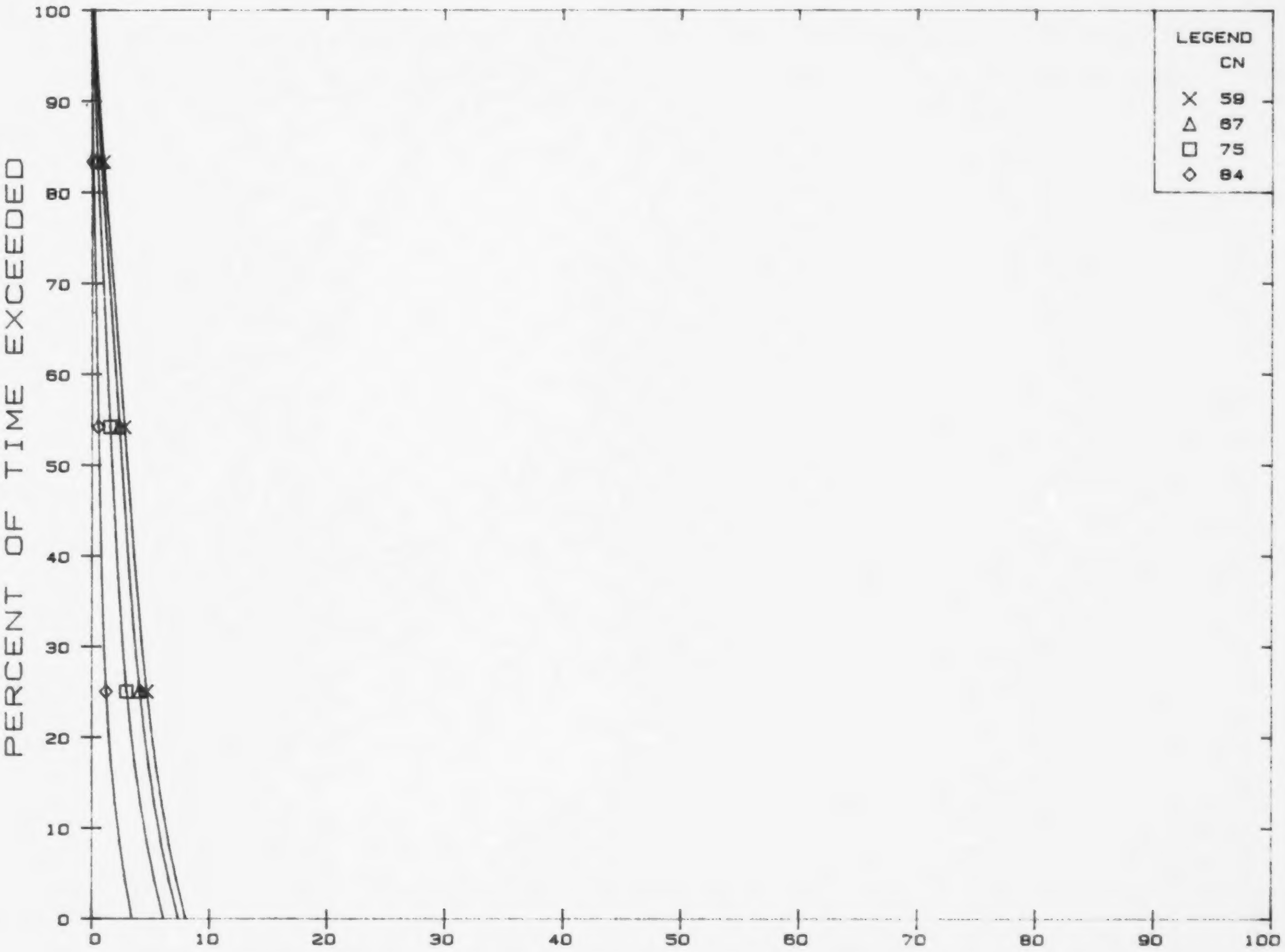


FIGURE A5-12 R=5. KS=.005



% OF APPLIED PESTICIDE LEACHED PER YEAR

FIGURE A5-13 R=5. KS=.010

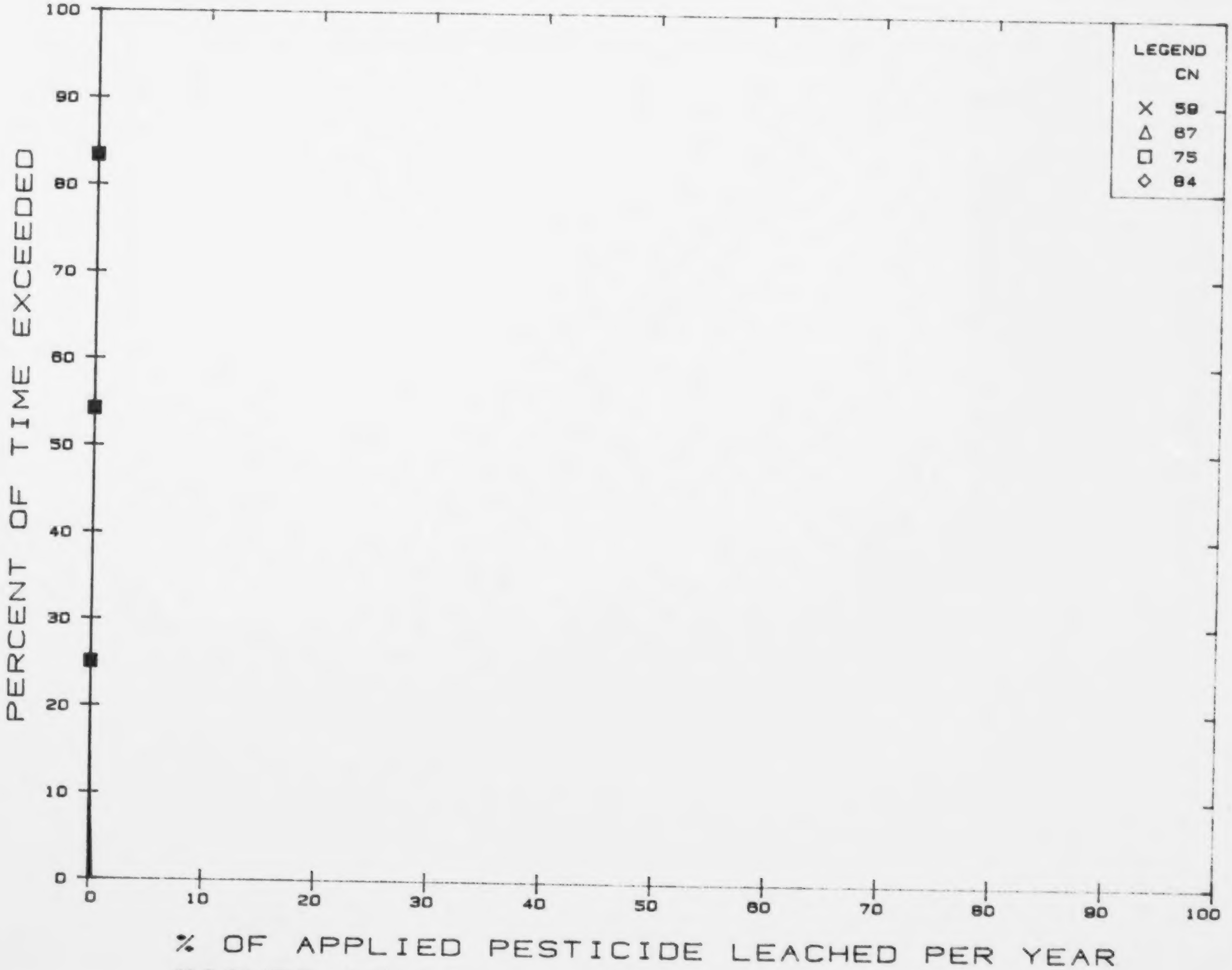


FIGURE A5-14 R=5. KS=.050

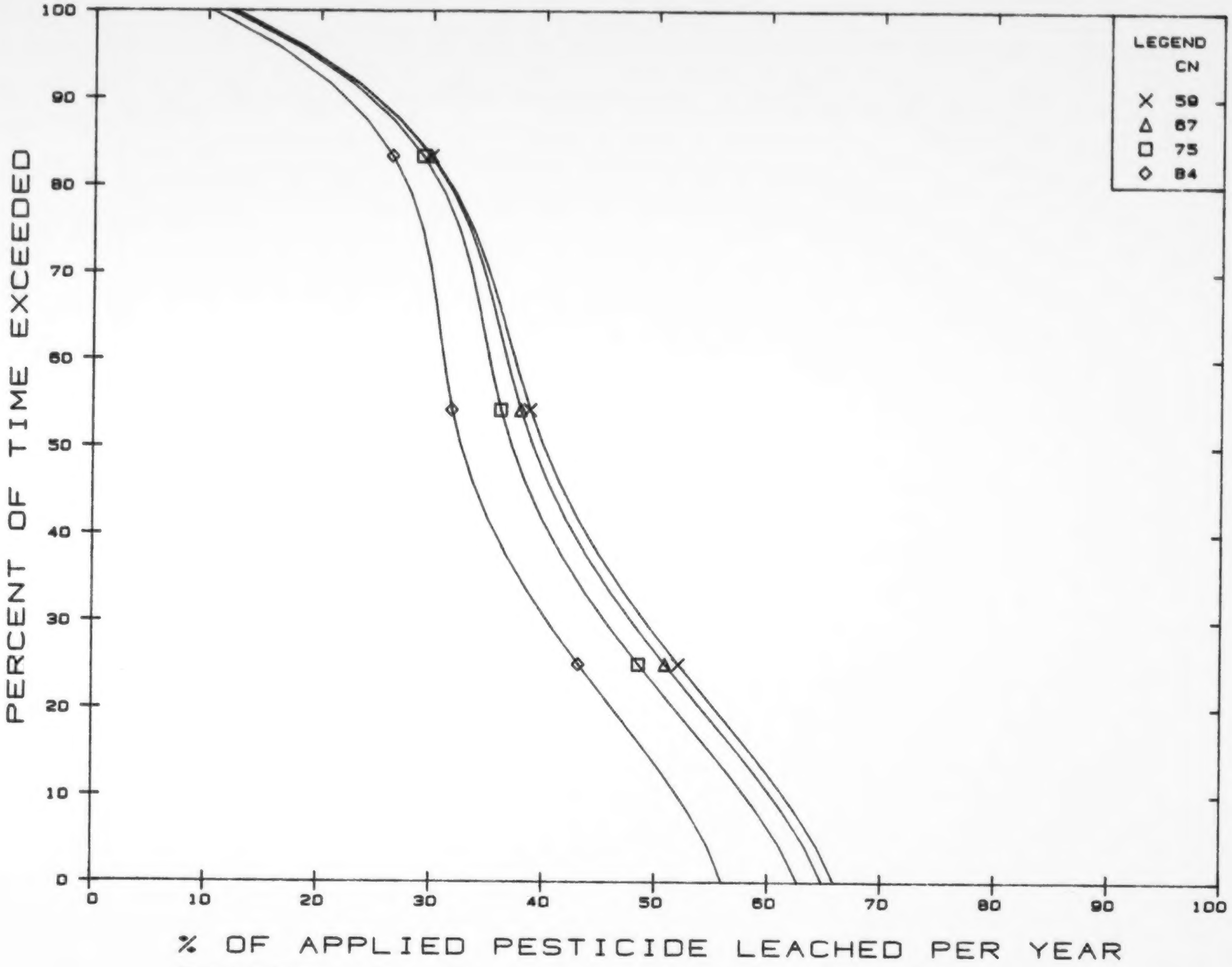


FIGURE A5-15 R=20. KS=.001

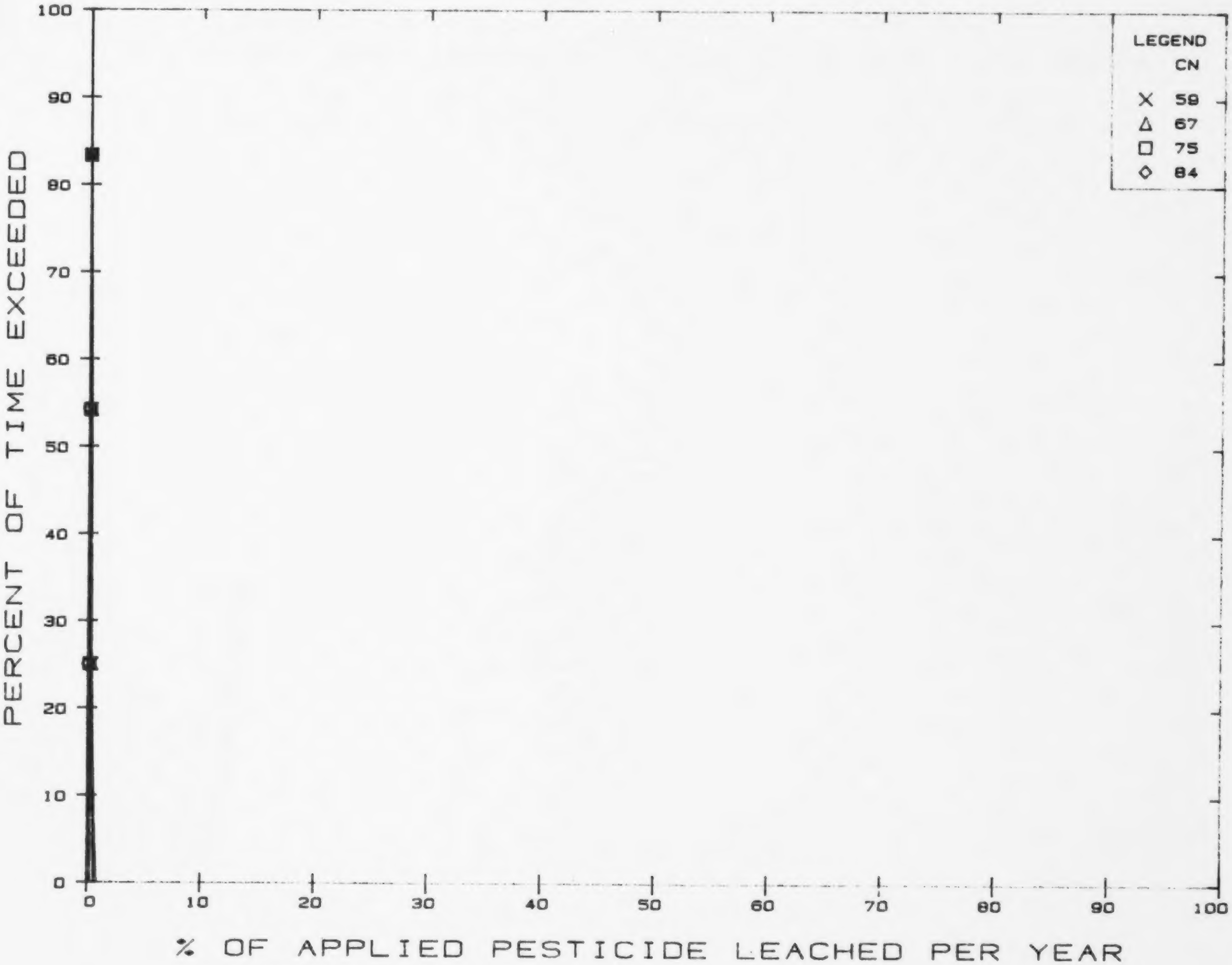


FIGURE A5-16 R=20. KS=.005

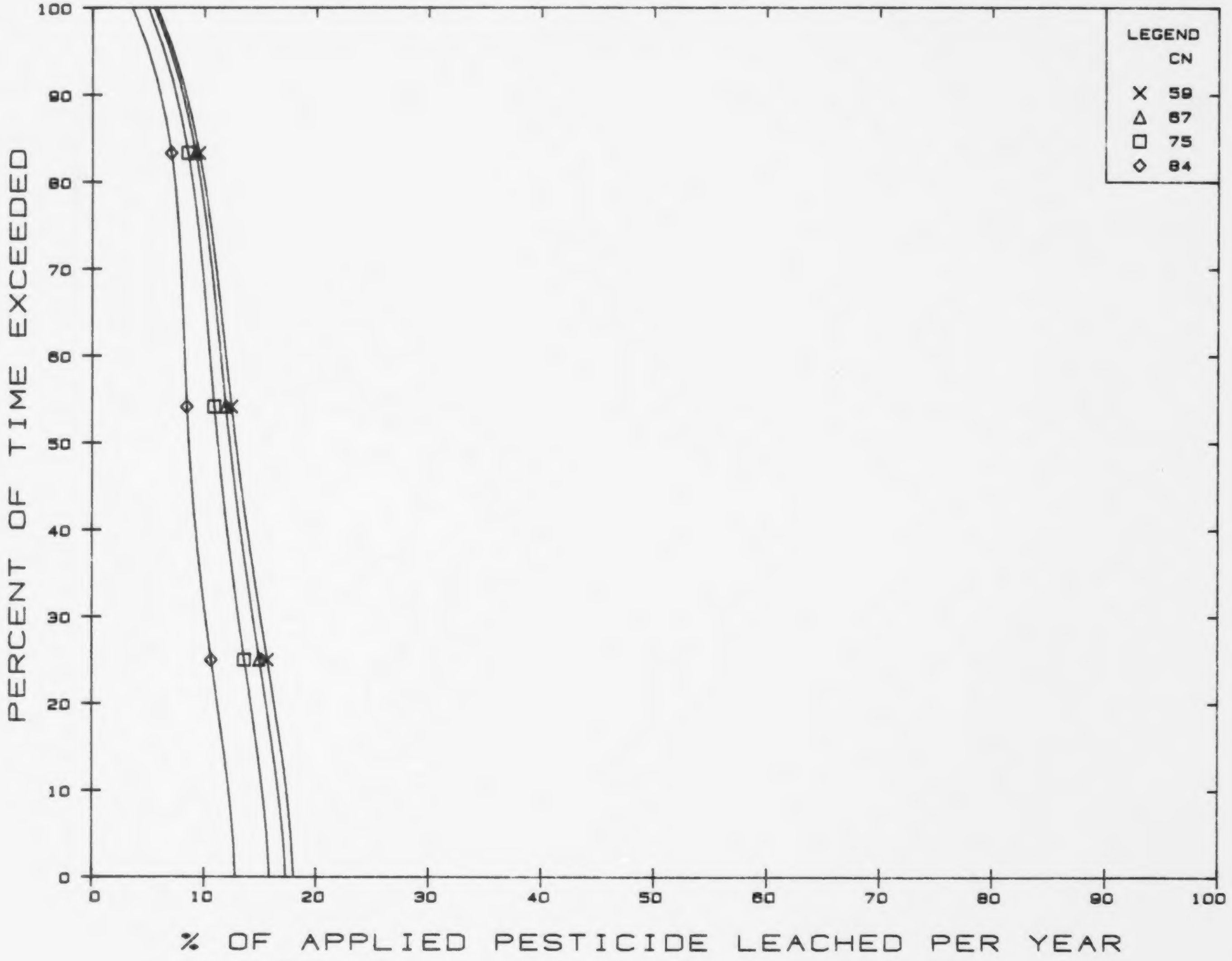


FIGURE A5-17 R=50. KS=.001

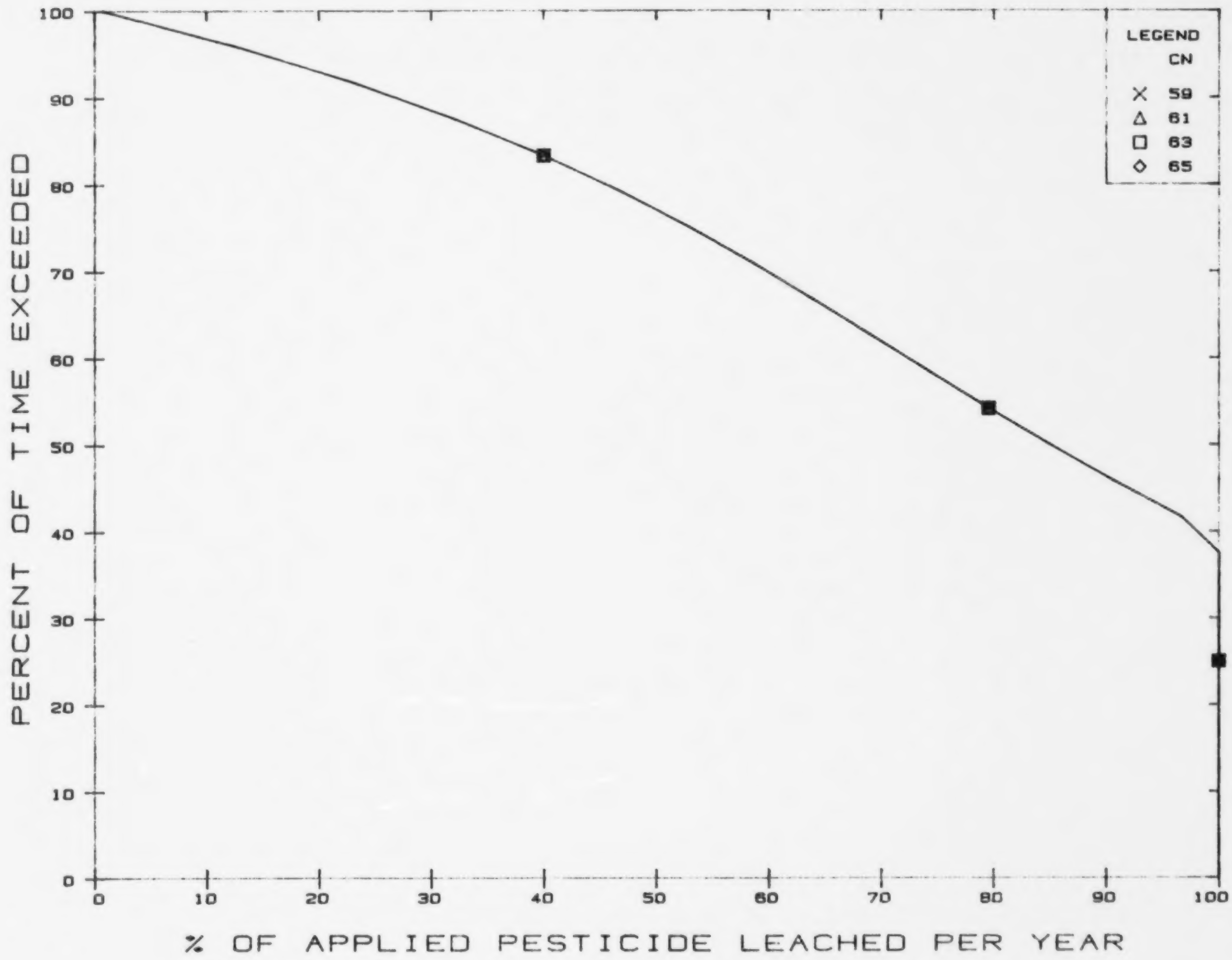
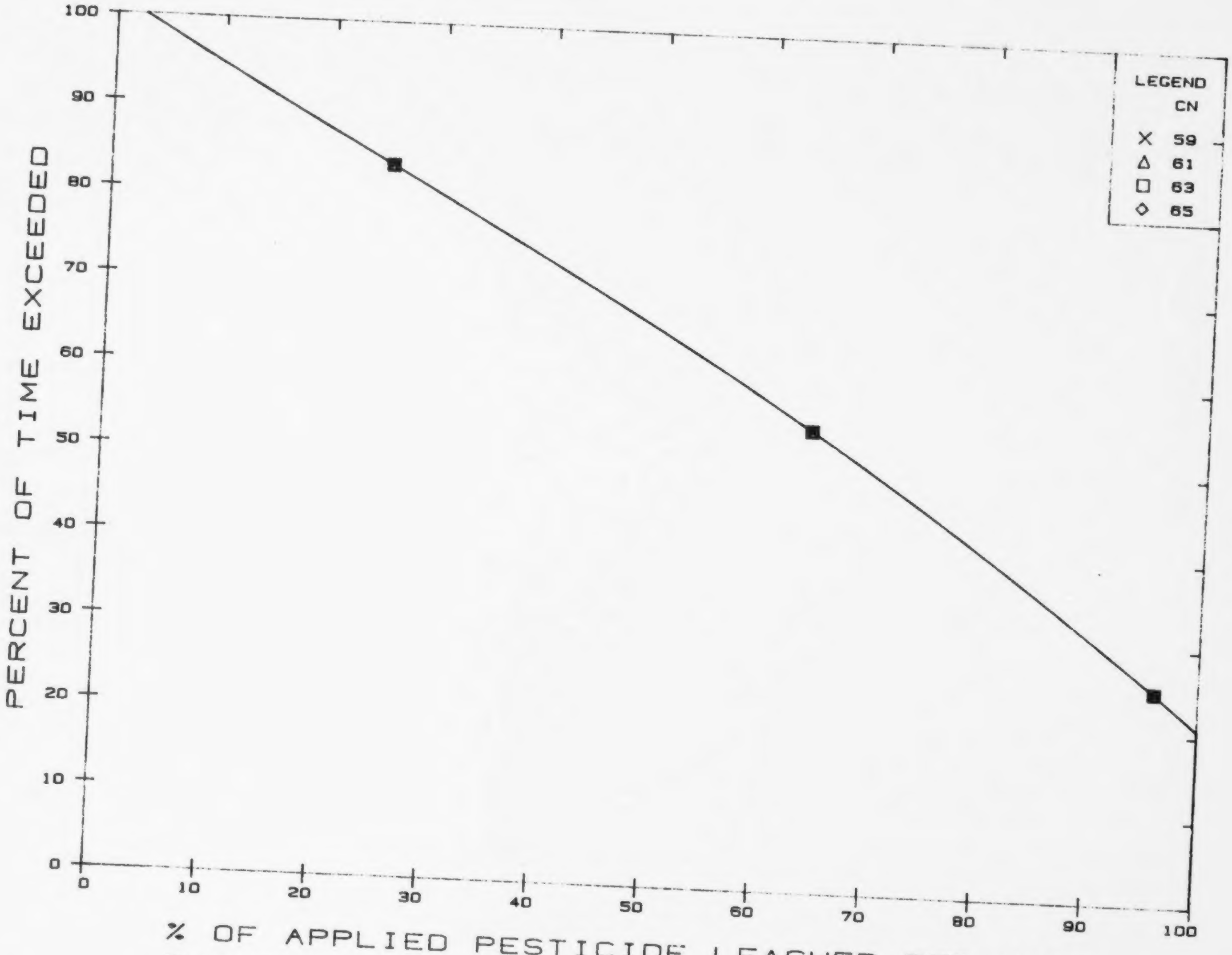


FIGURE A6-1 R=1. KS=.001



% OF APPLIED PESTICIDE LEACHED PER YEAR

FIGURE A6-2 R=1. KS=.005

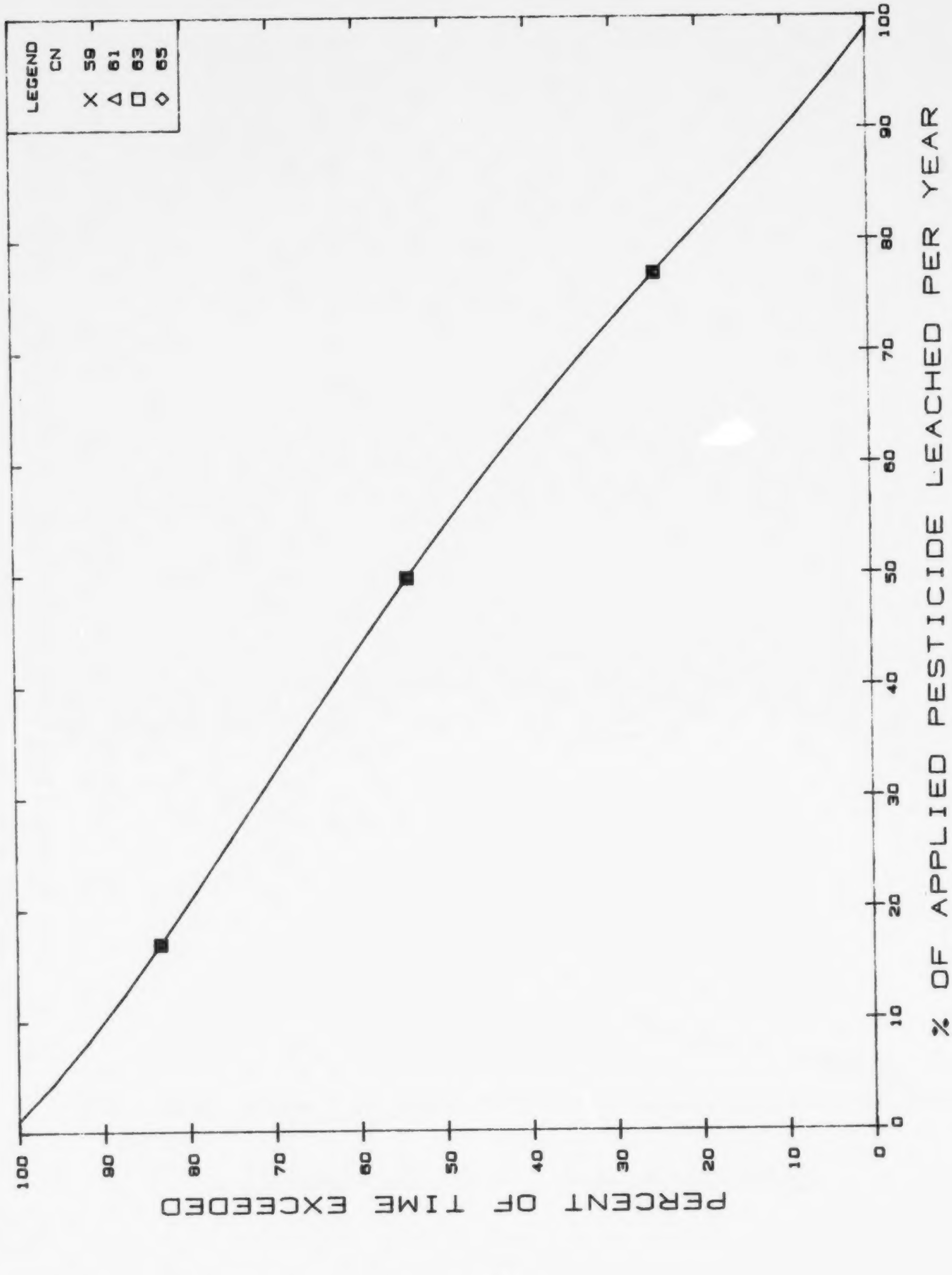


FIGURE A6-3   R=1.   KS=.010

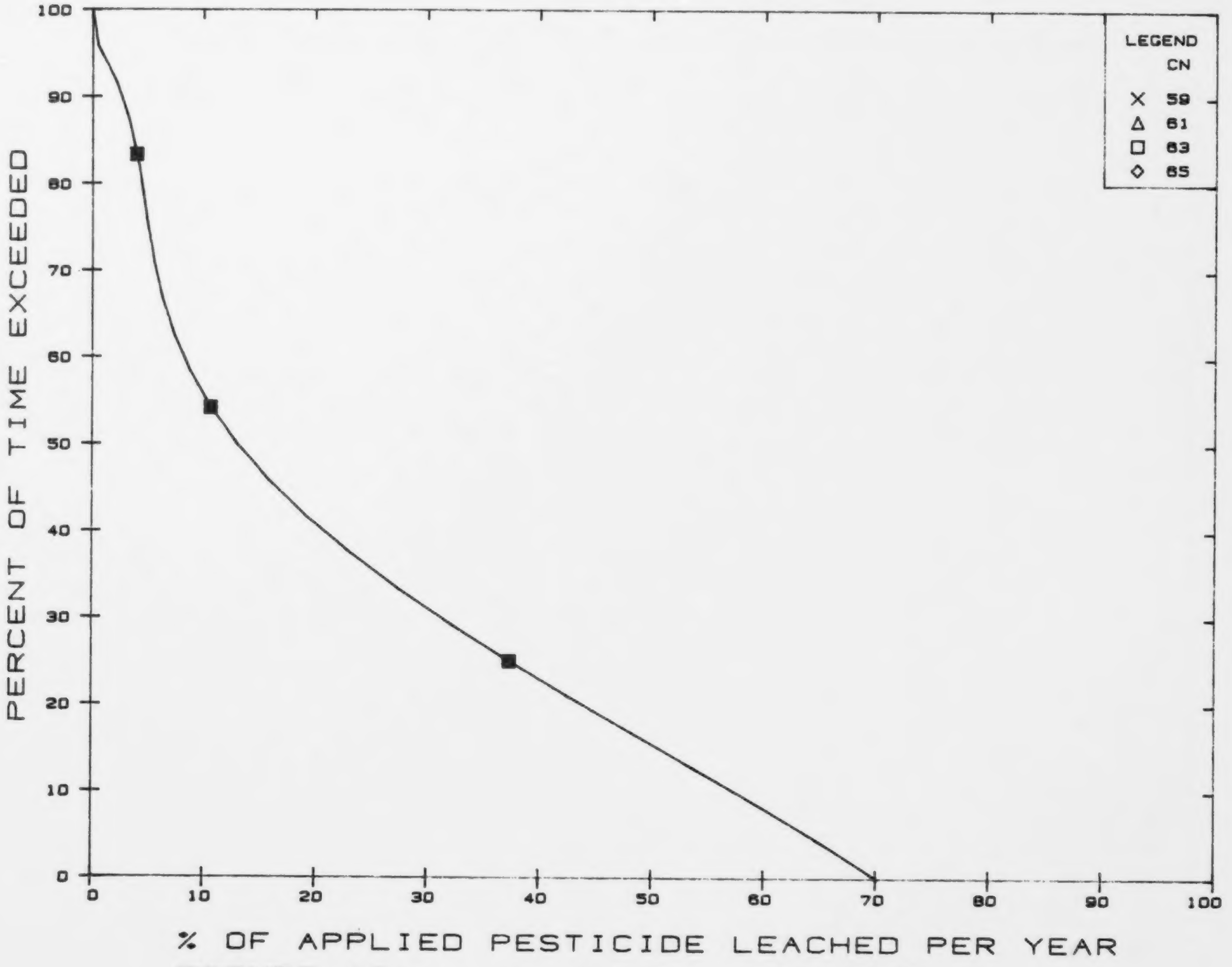


FIGURE A6-4 R=1. KS=.050

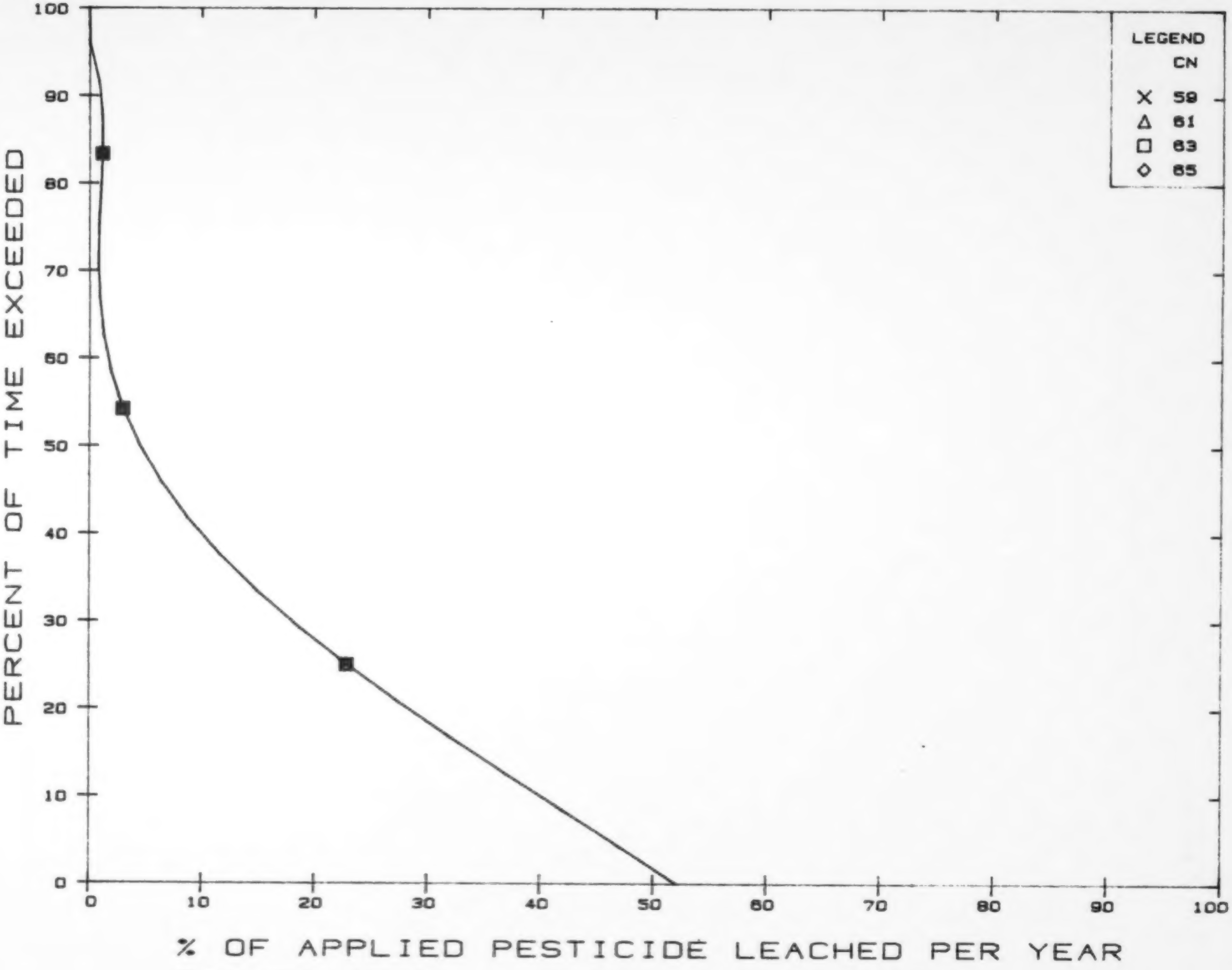


FIGURE A6-5 R=1. KS=.100

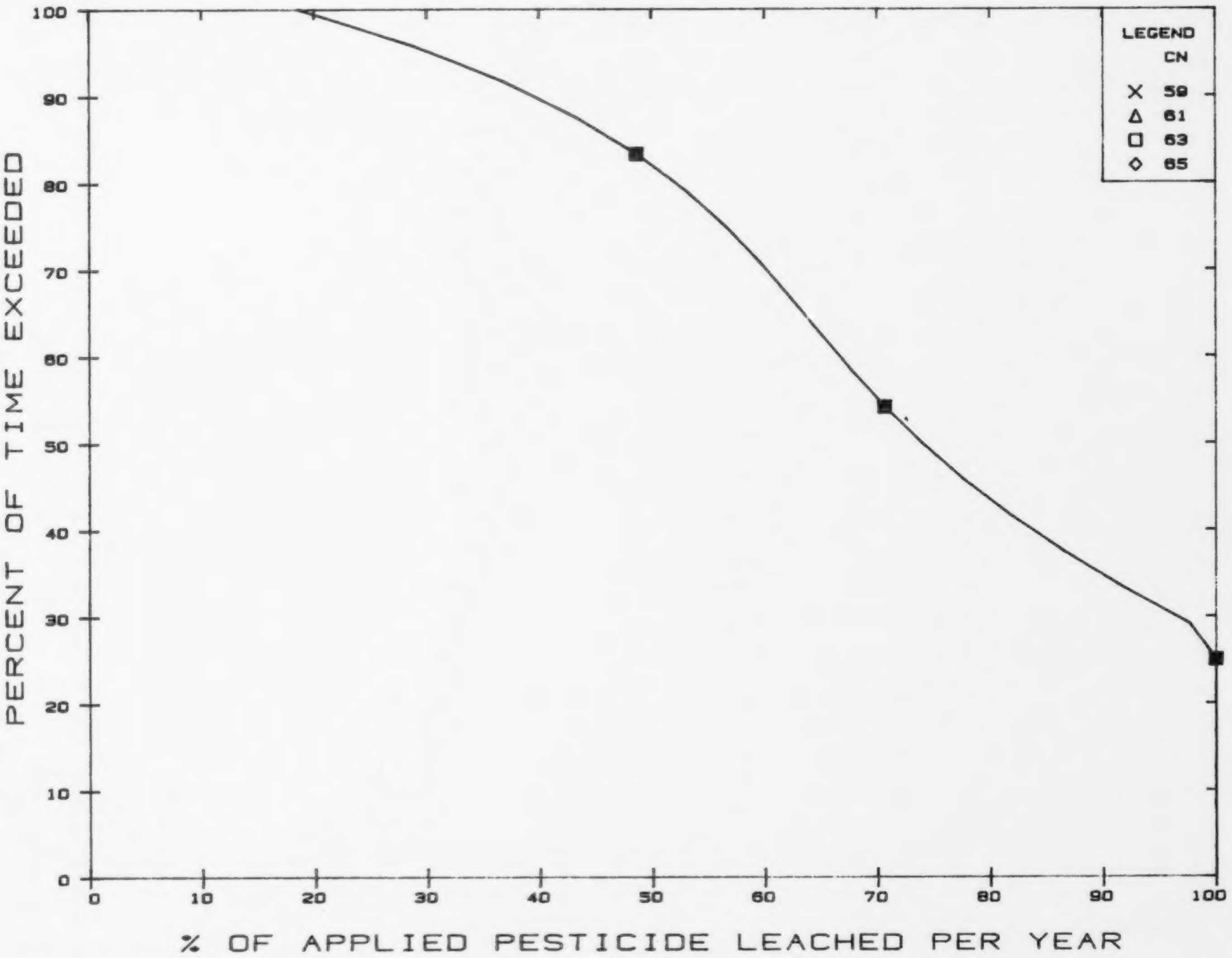


FIGURE A6-6 R=3. KS=.001

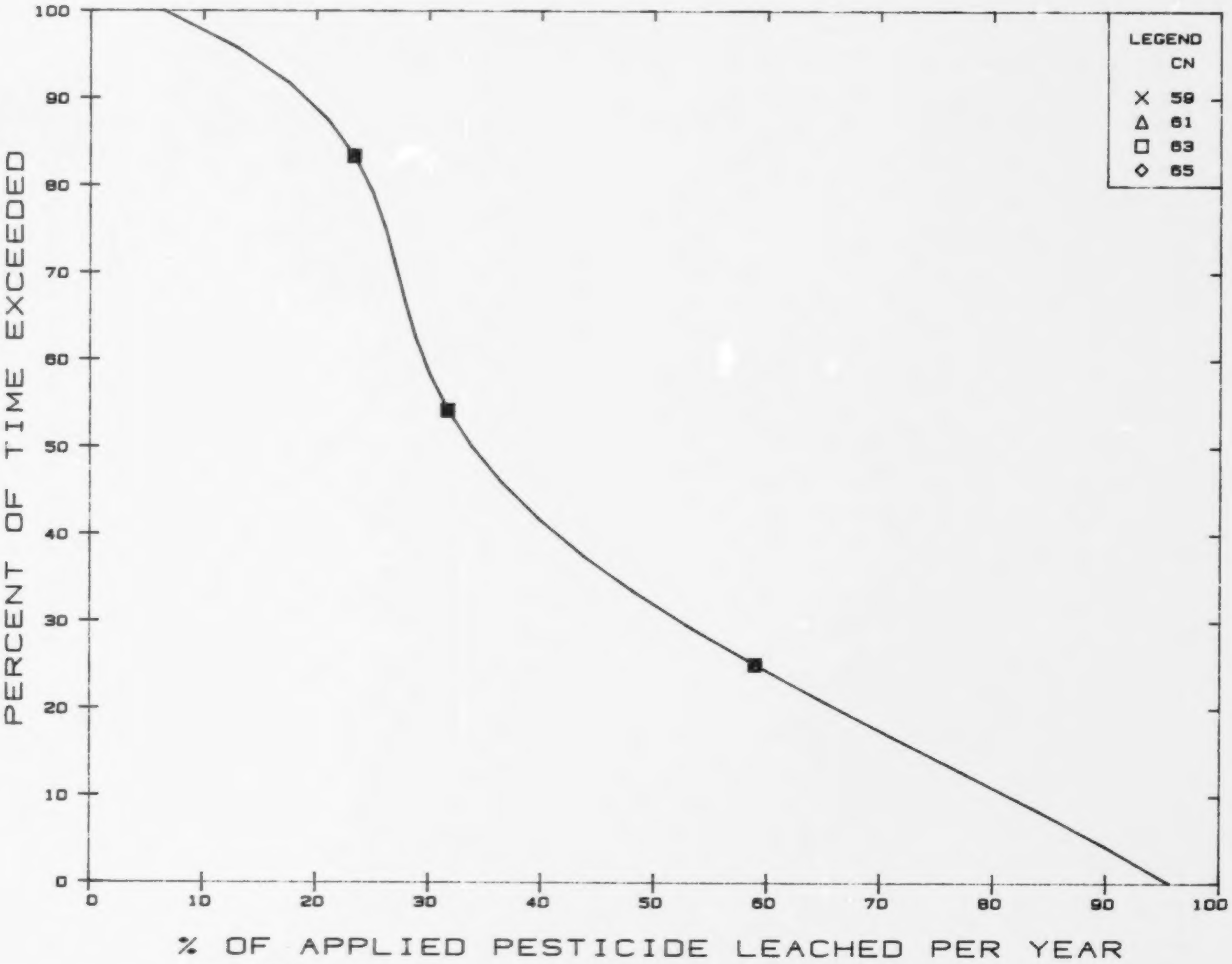


FIGURE A6-7 R=3. KS=.005

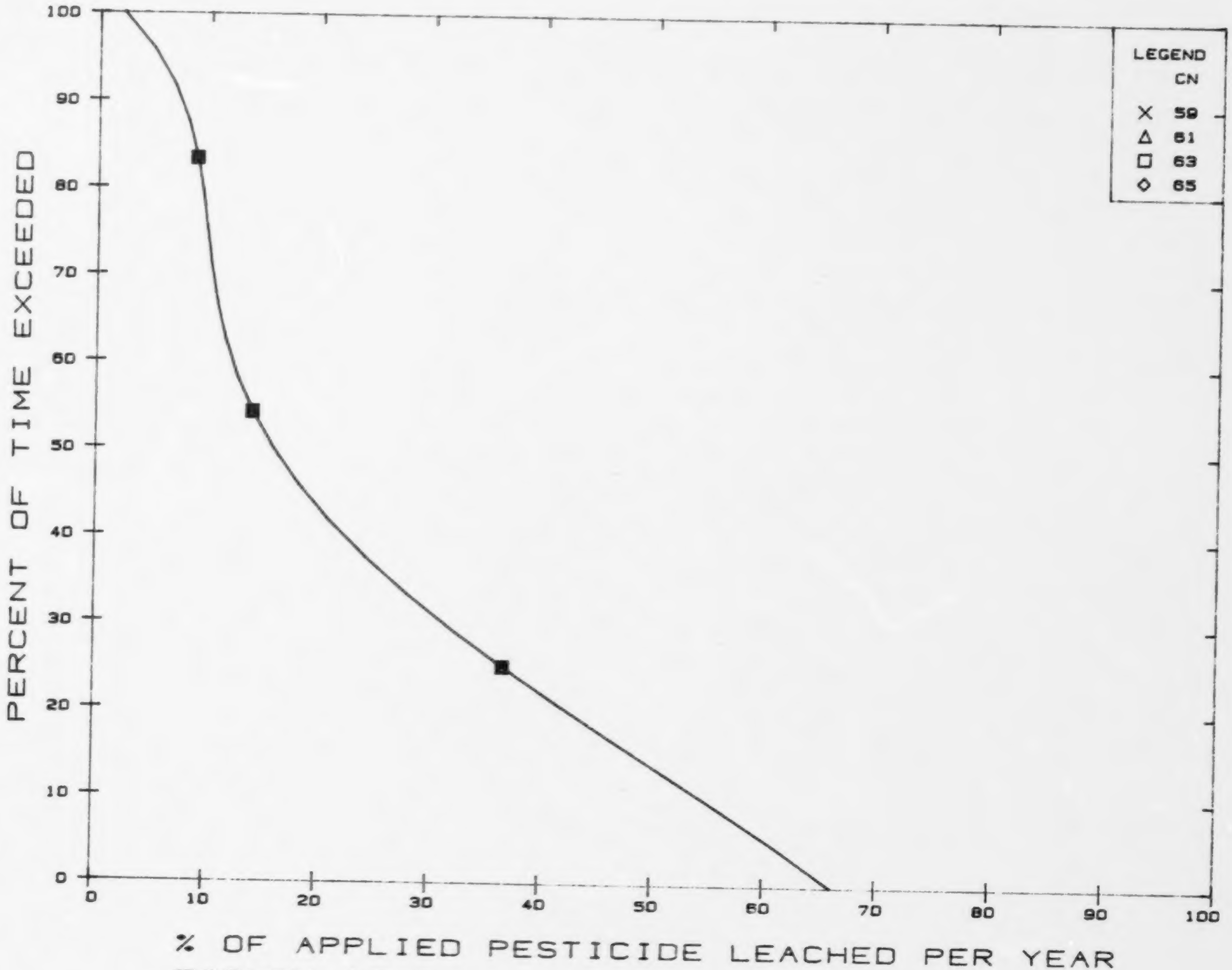


FIGURE A6-8 R=3. KS=.010

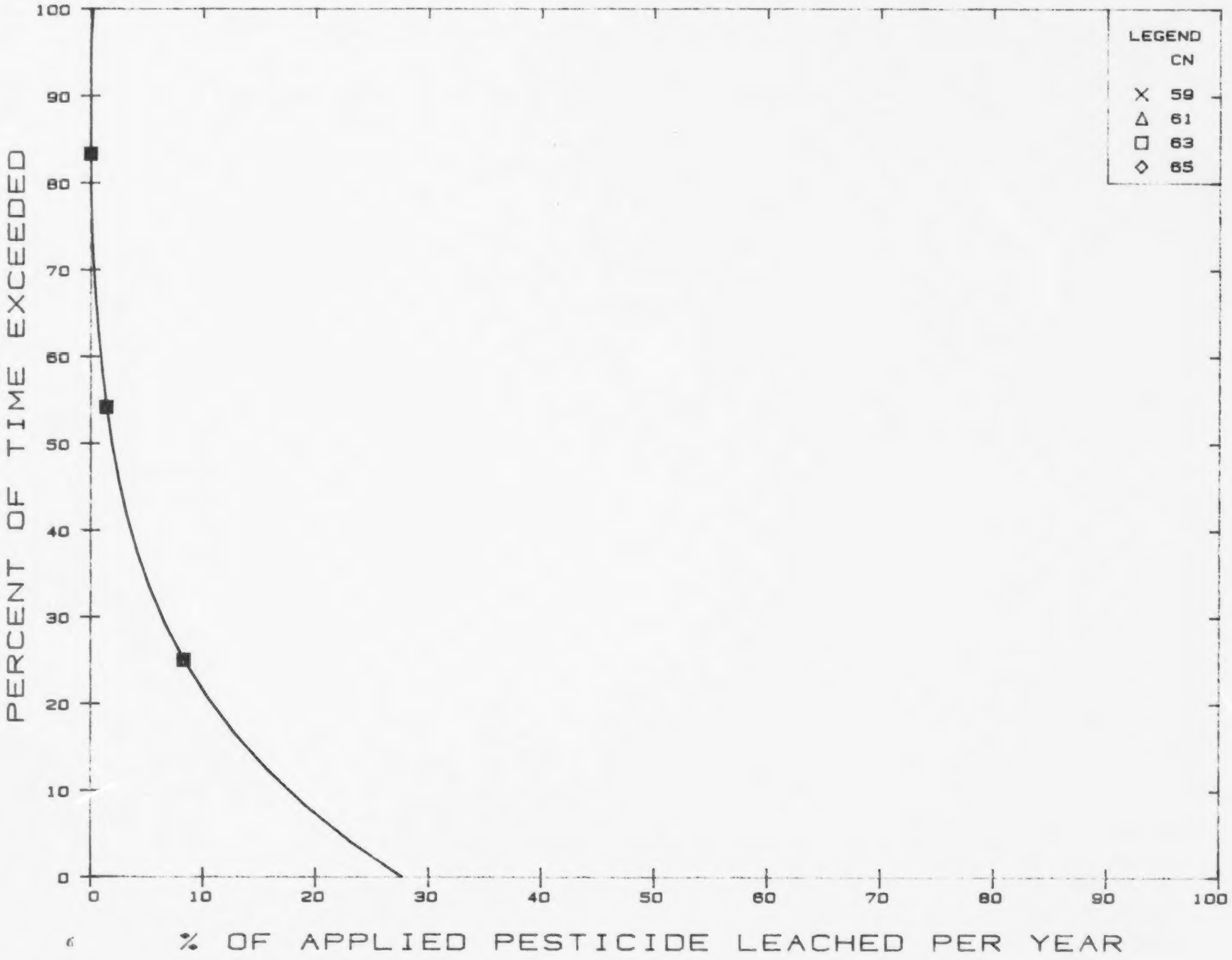


FIGURE A6-9 R=3. KS=.050

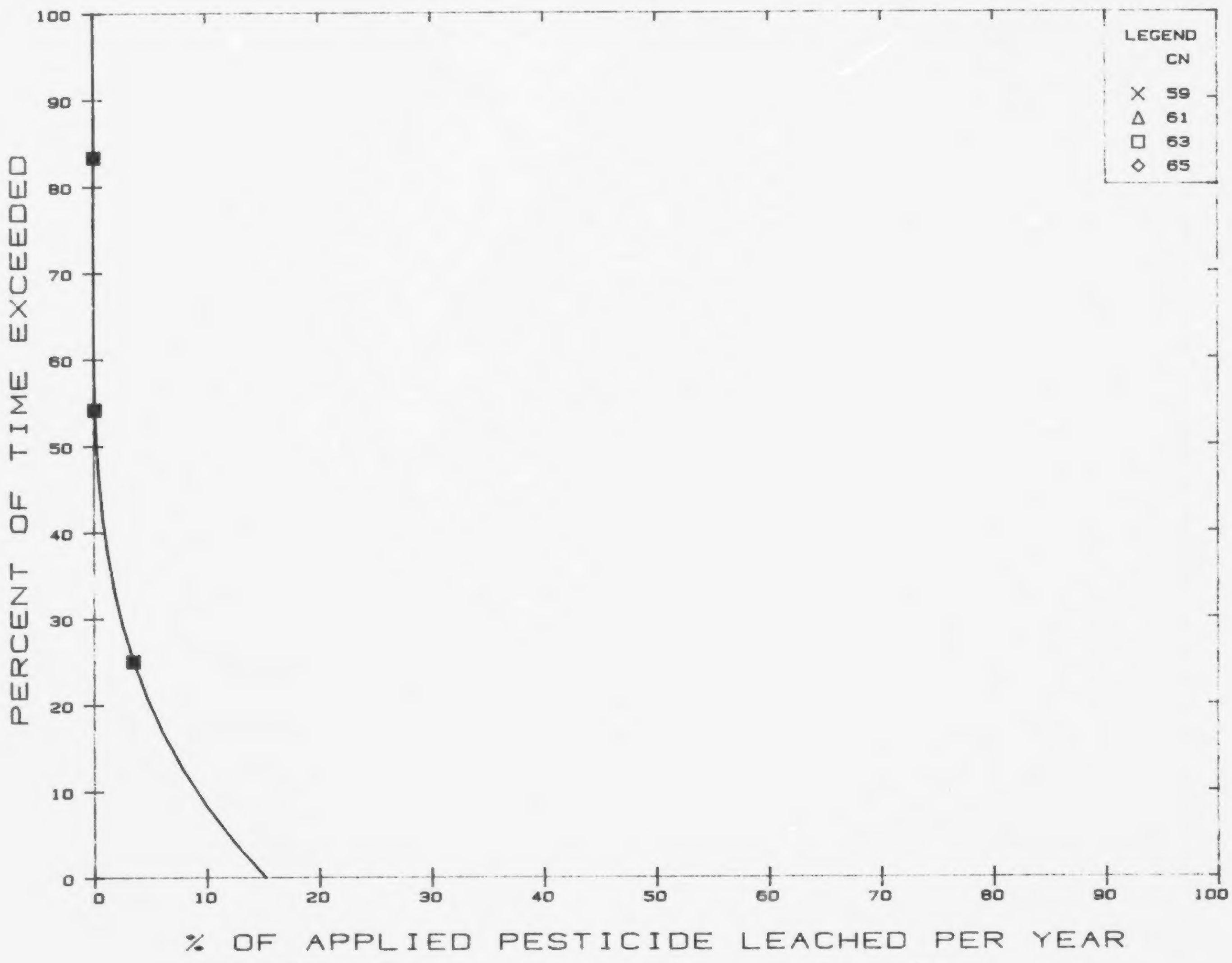


FIGURE A6-10 R=3. KS=.100

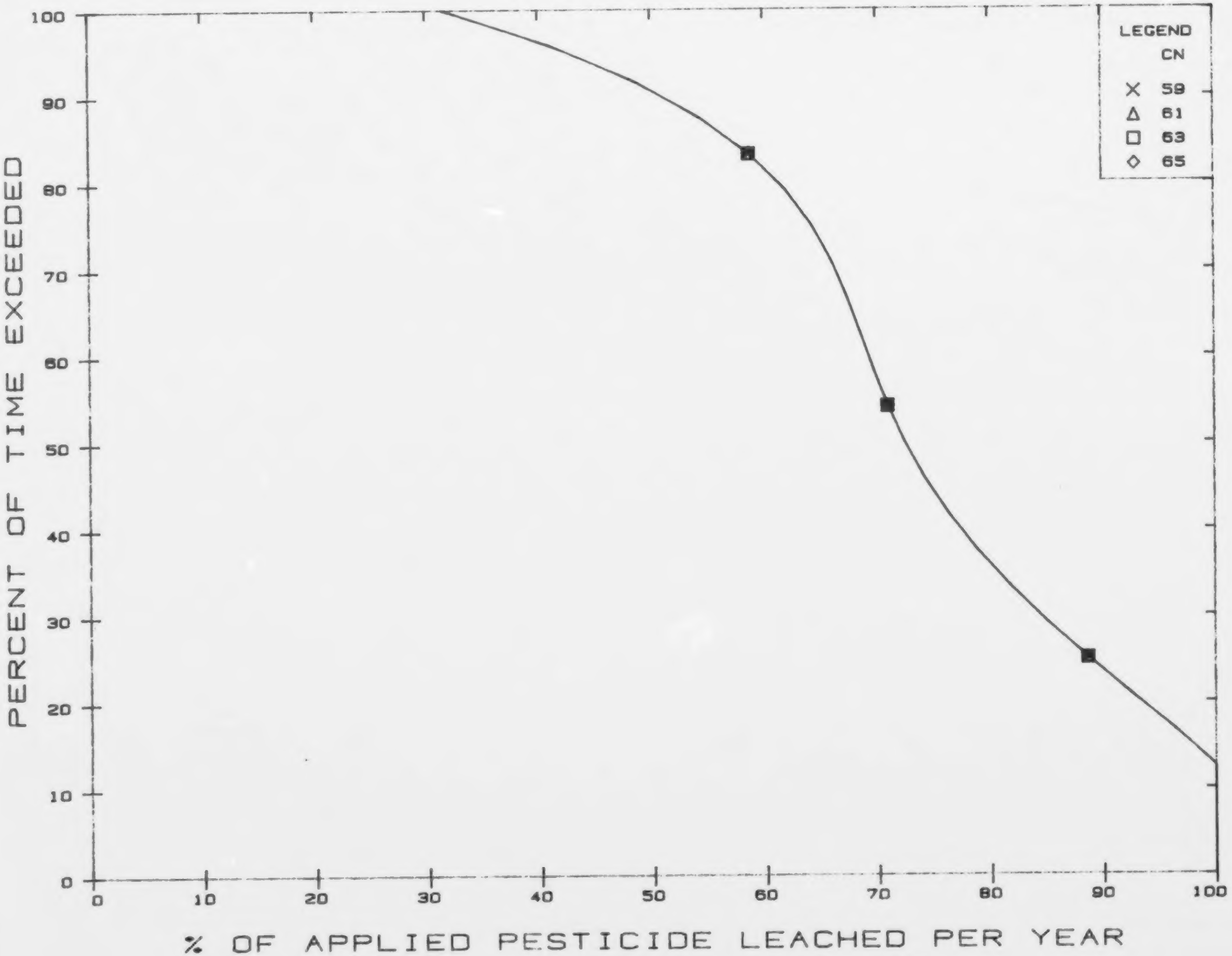


FIGURE A6-11 R=5. KS=.001

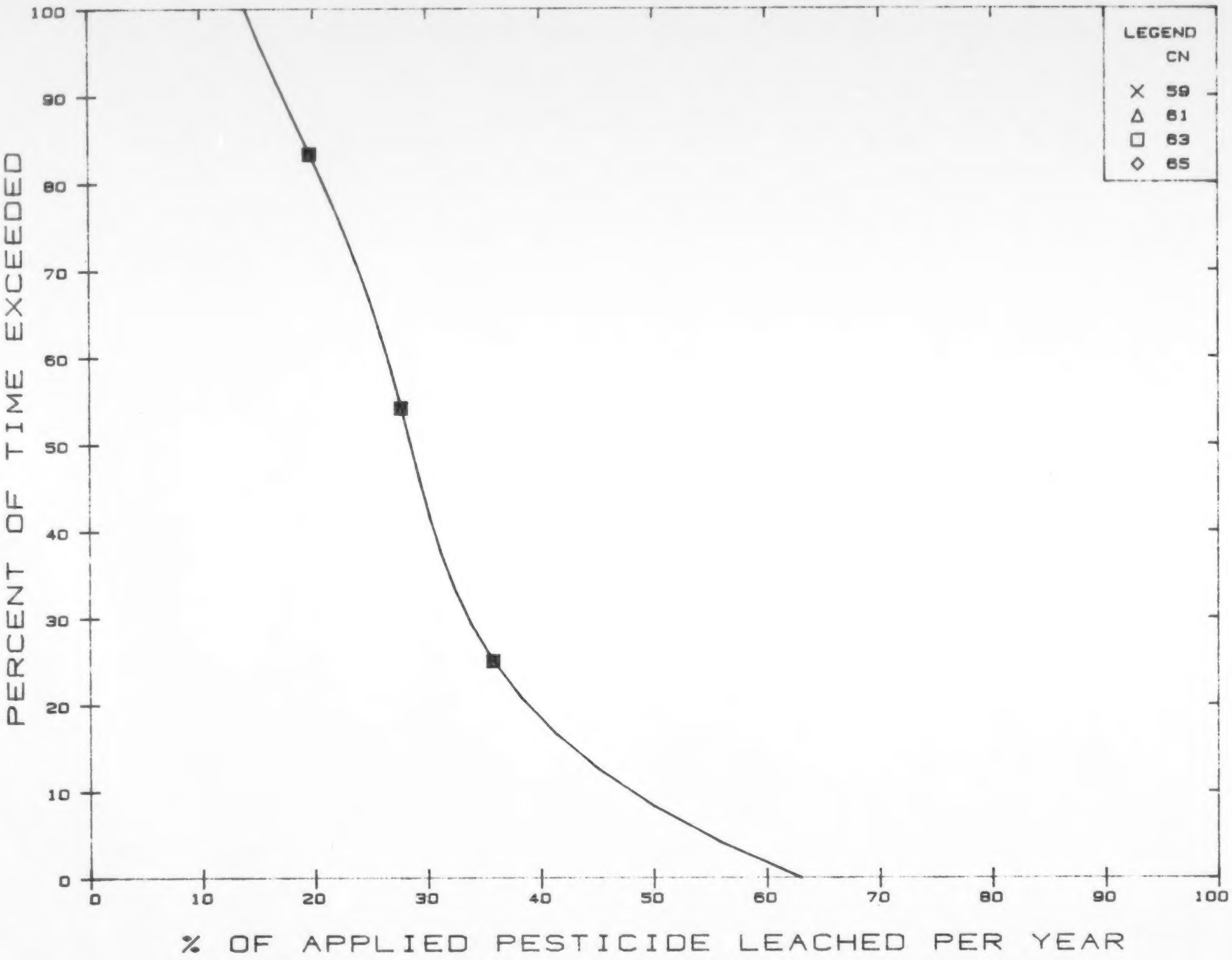


FIGURE A6-12 R=5. KS=.005

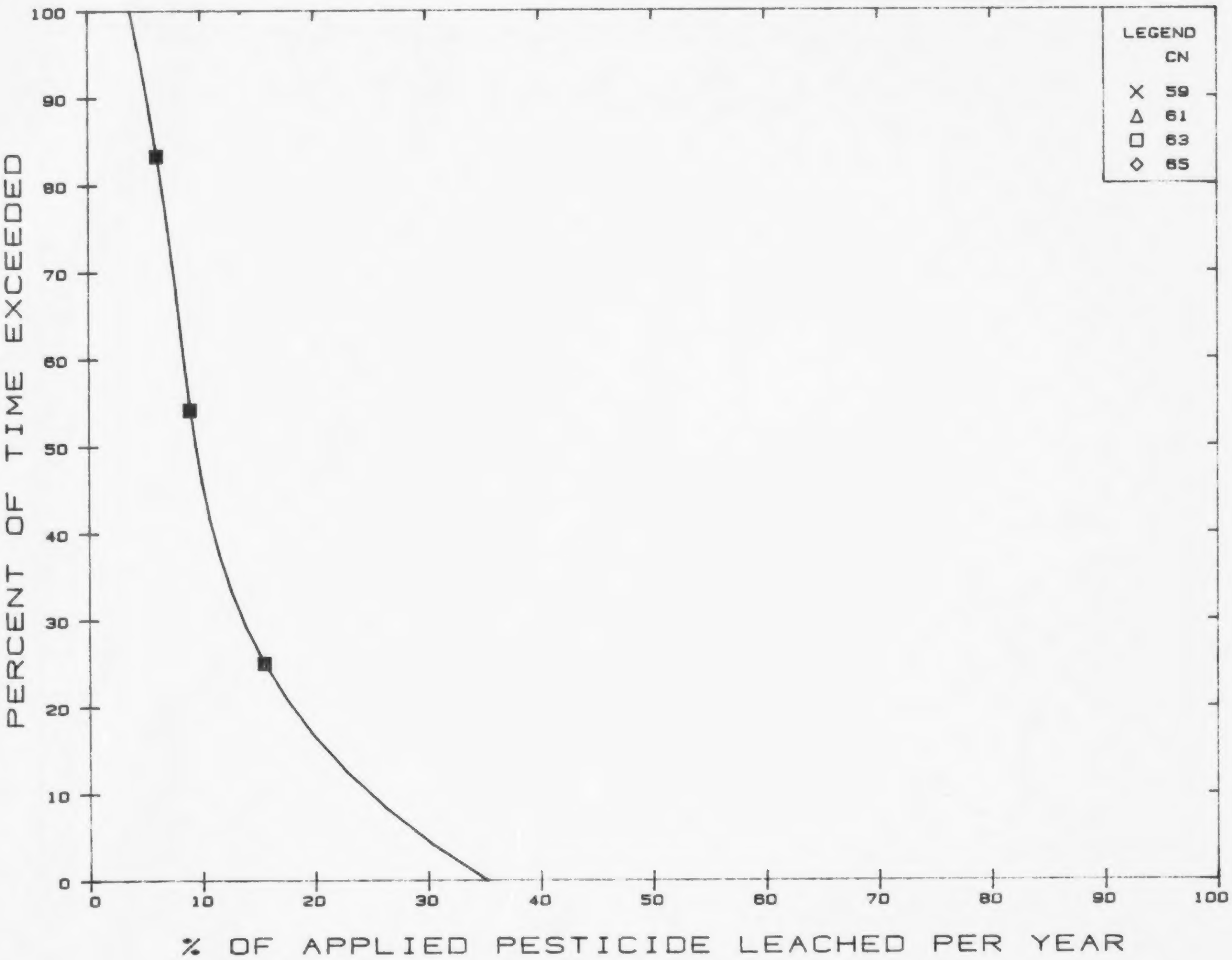


FIGURE A6-13 R=5. KS=.010

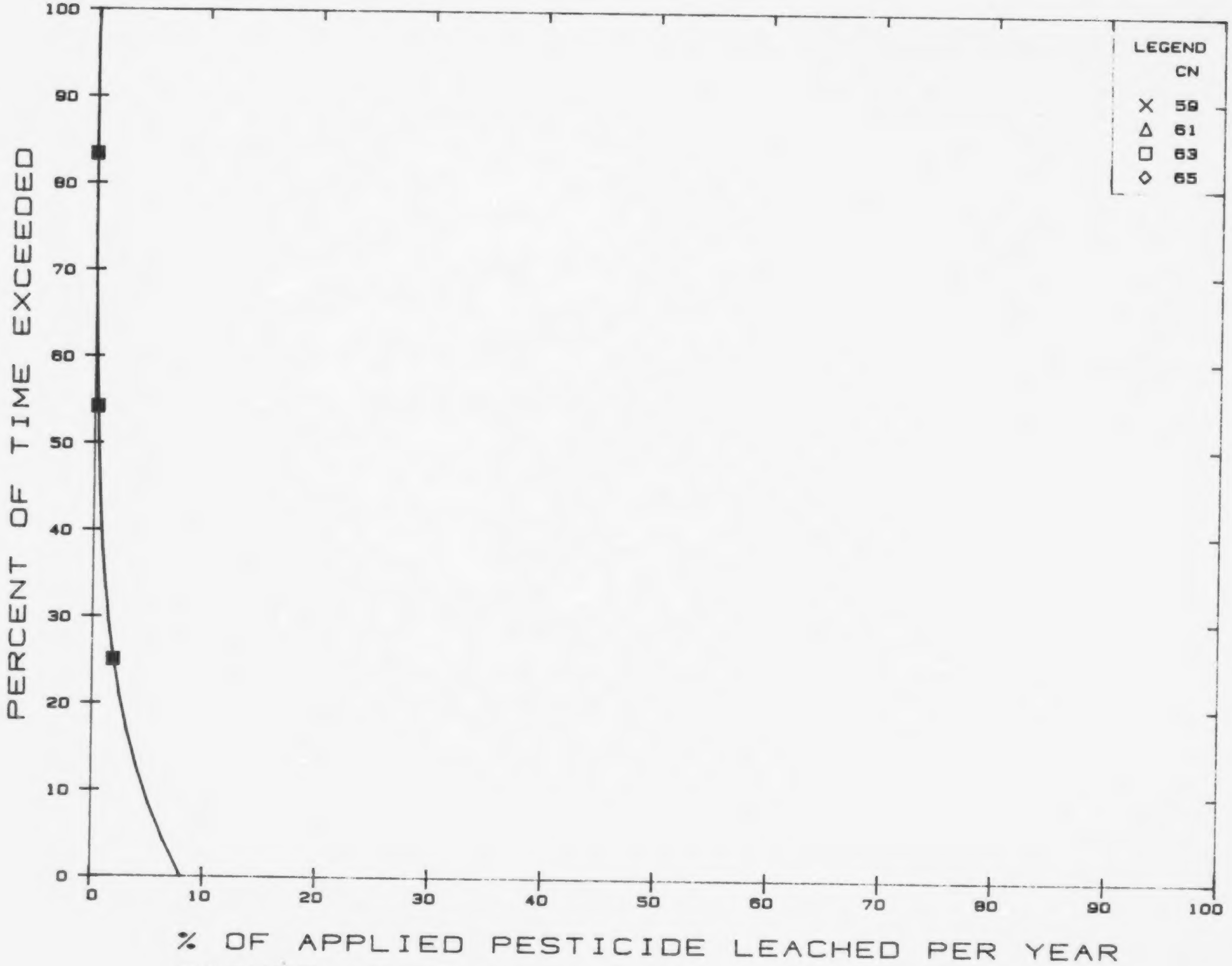
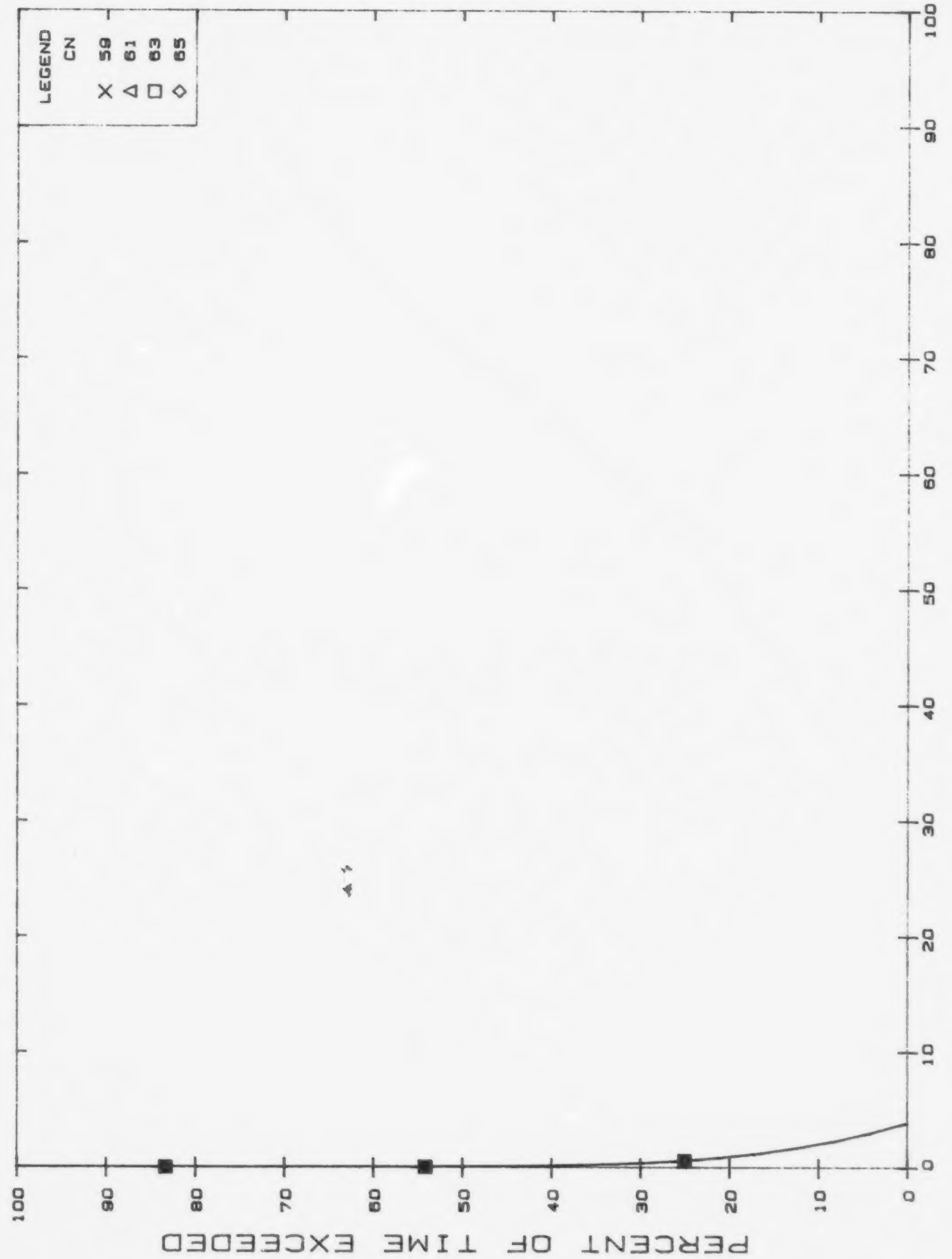


FIGURE A6-14 R=5. KS=.050



% OF APPLIED PESTICIDE LEACHED PER YEAR

FIGURE A6-15 R=5. KS=.100

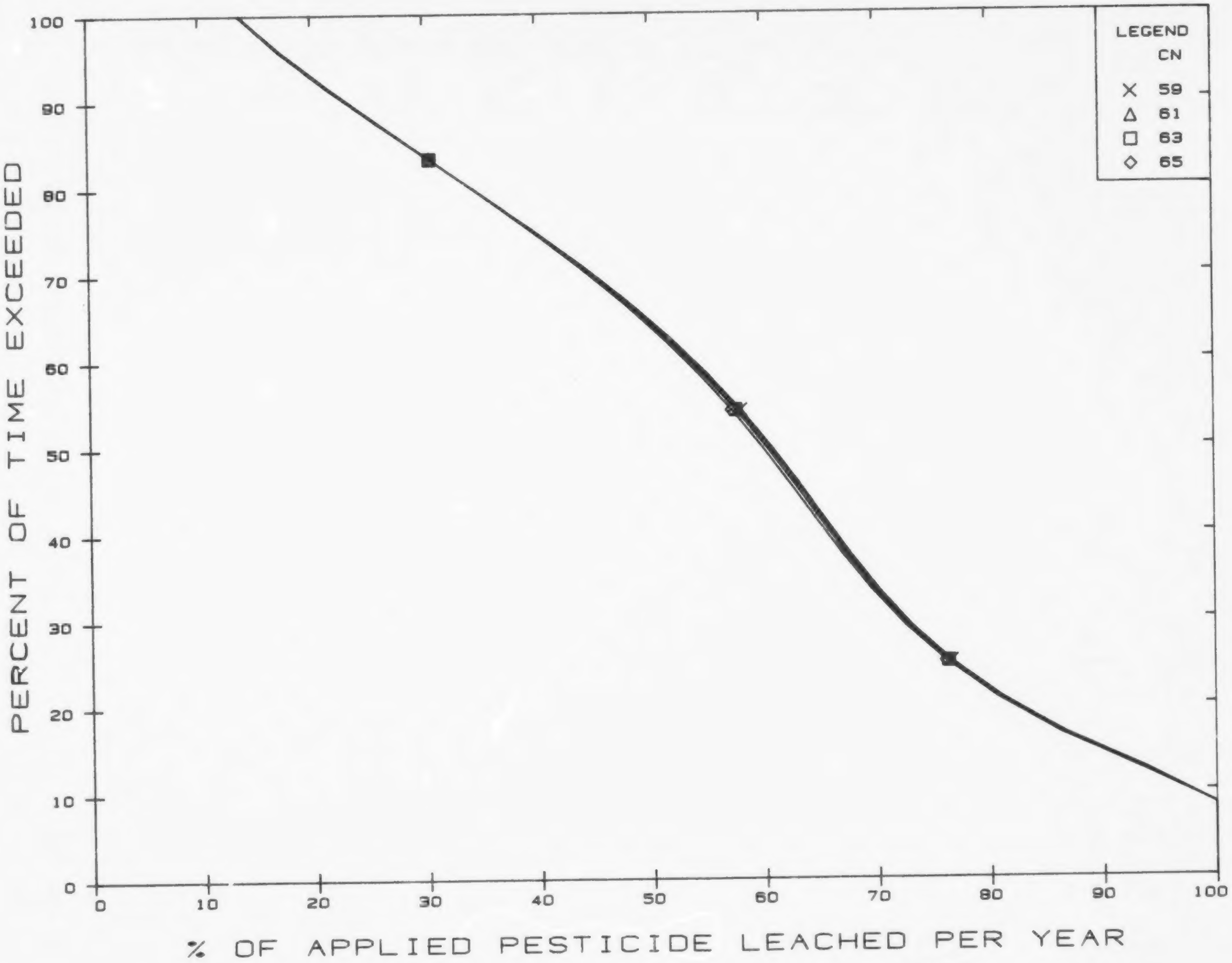


FIGURE A6-16 R=20. KS=.001

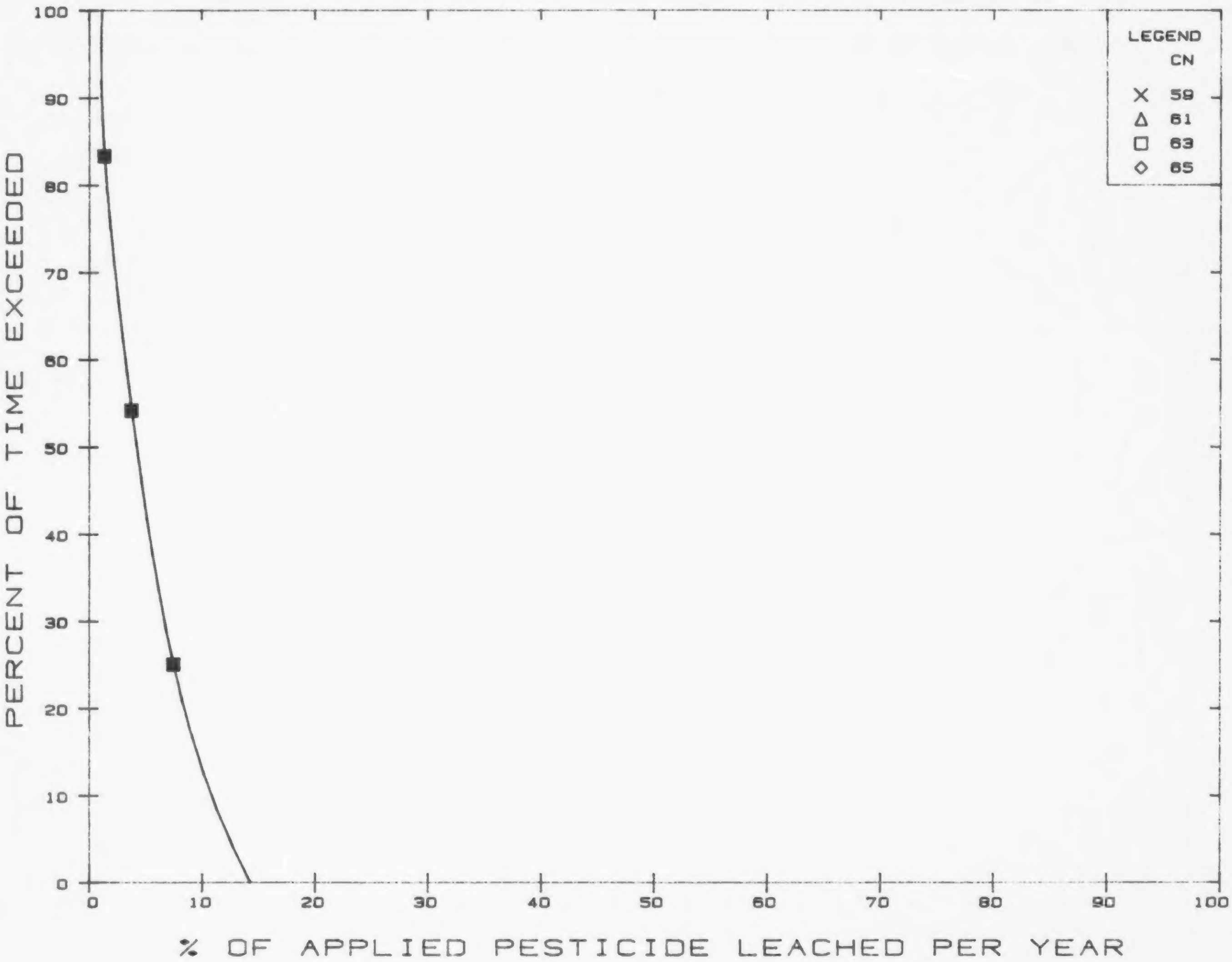


FIGURE A6-17 R=20. KS=.005

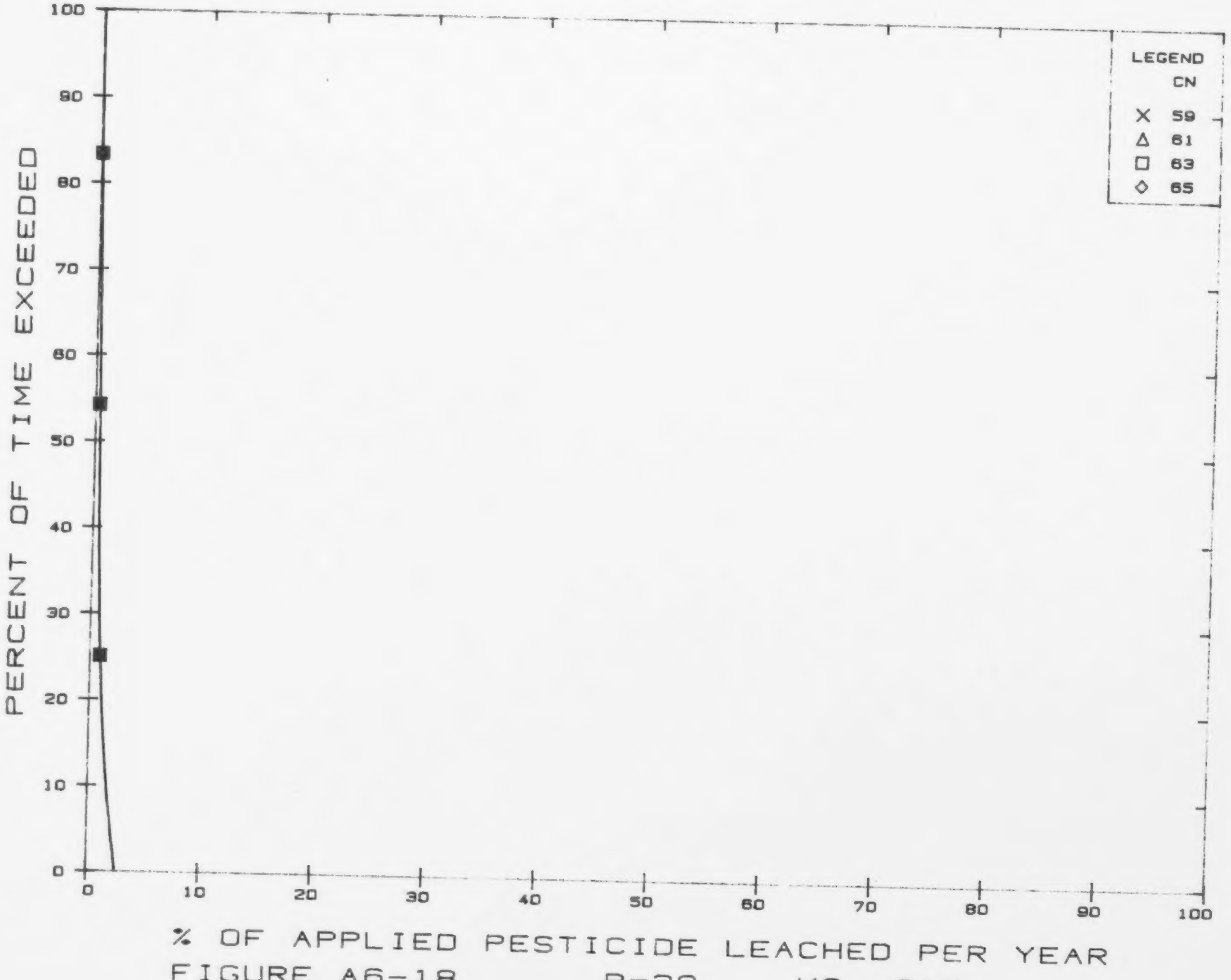


FIGURE A6-18 R=20. KS=.010

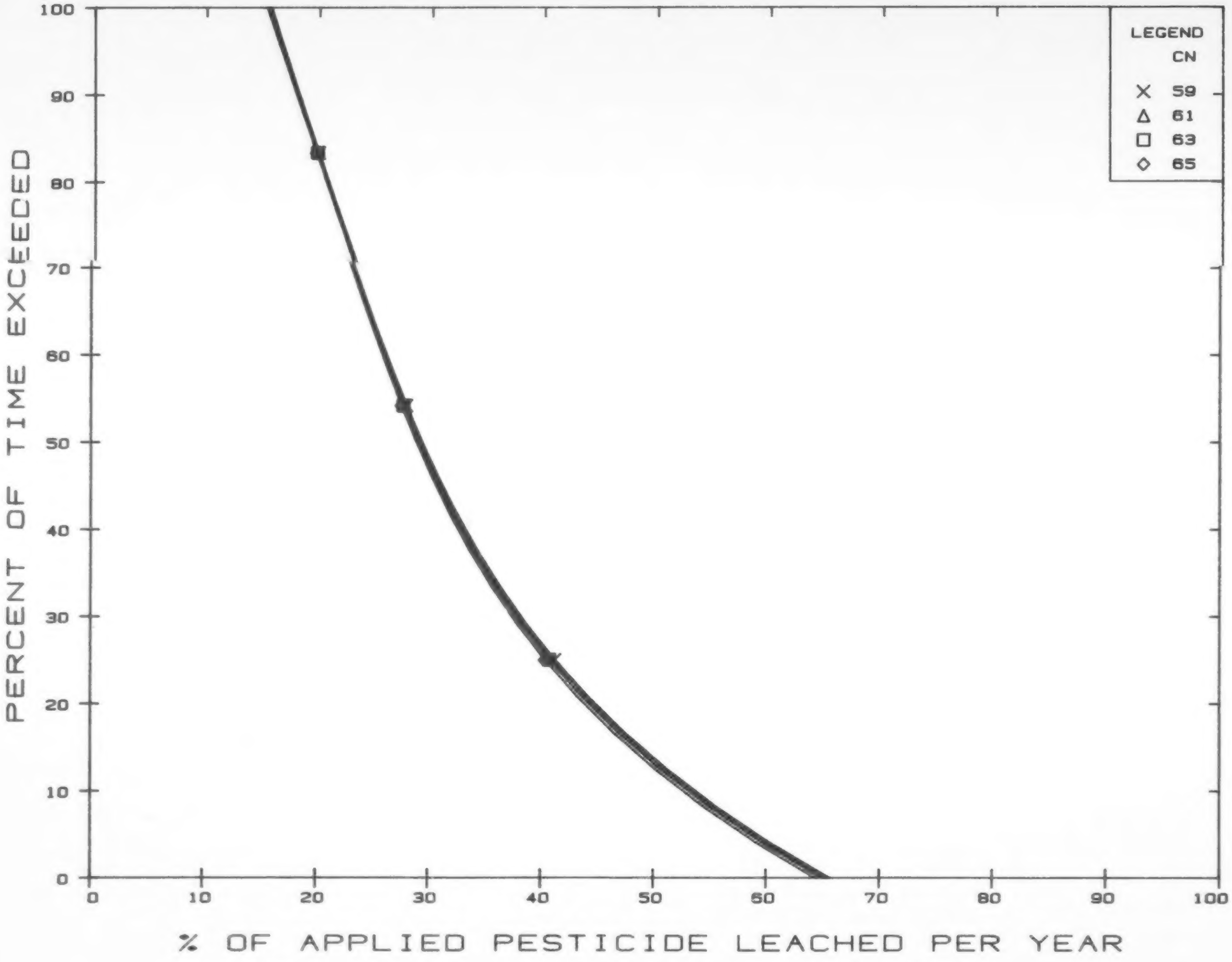


FIGURE A6-19 R=50. KS=.001

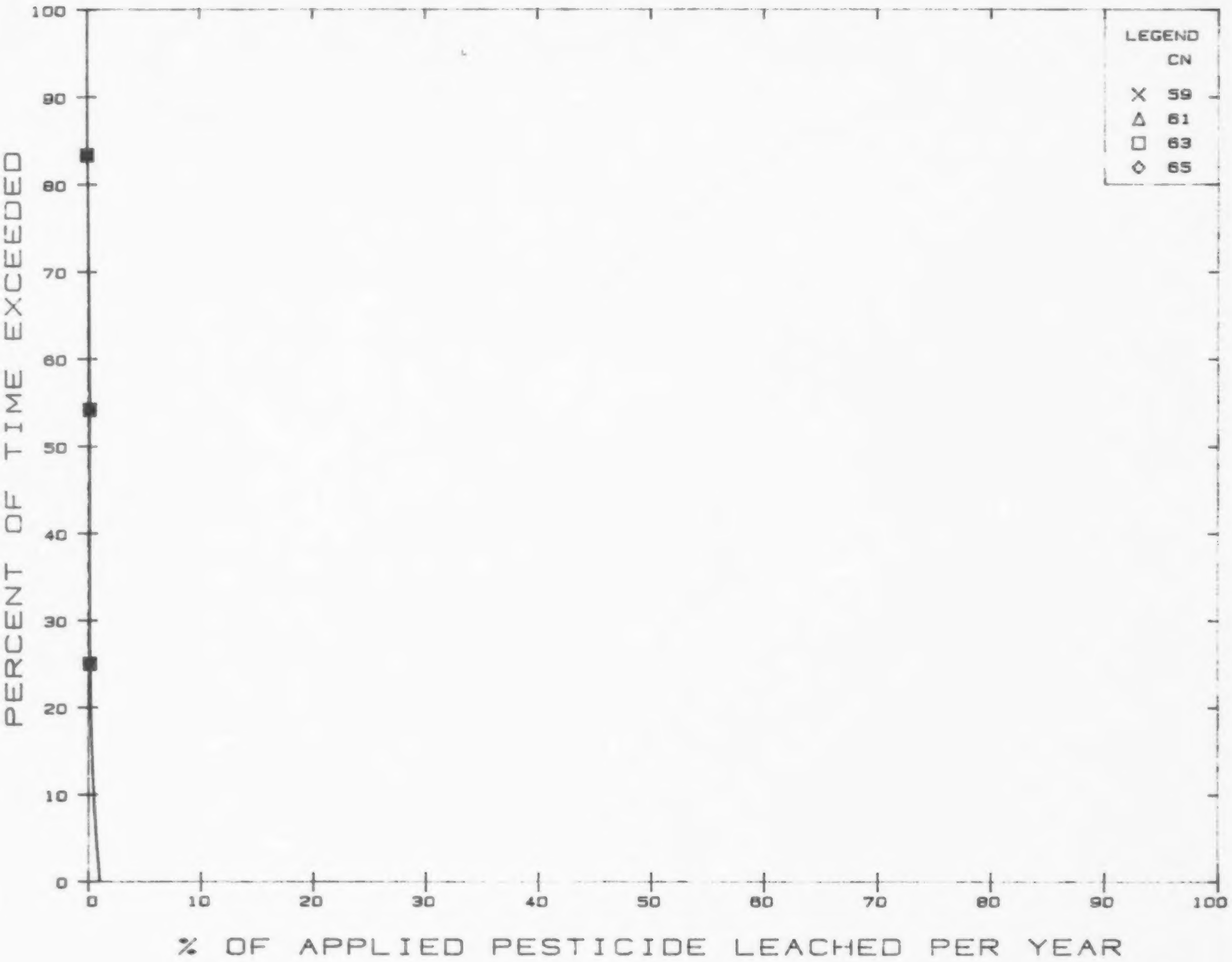


FIGURE A6-20 R=50. KS=.005

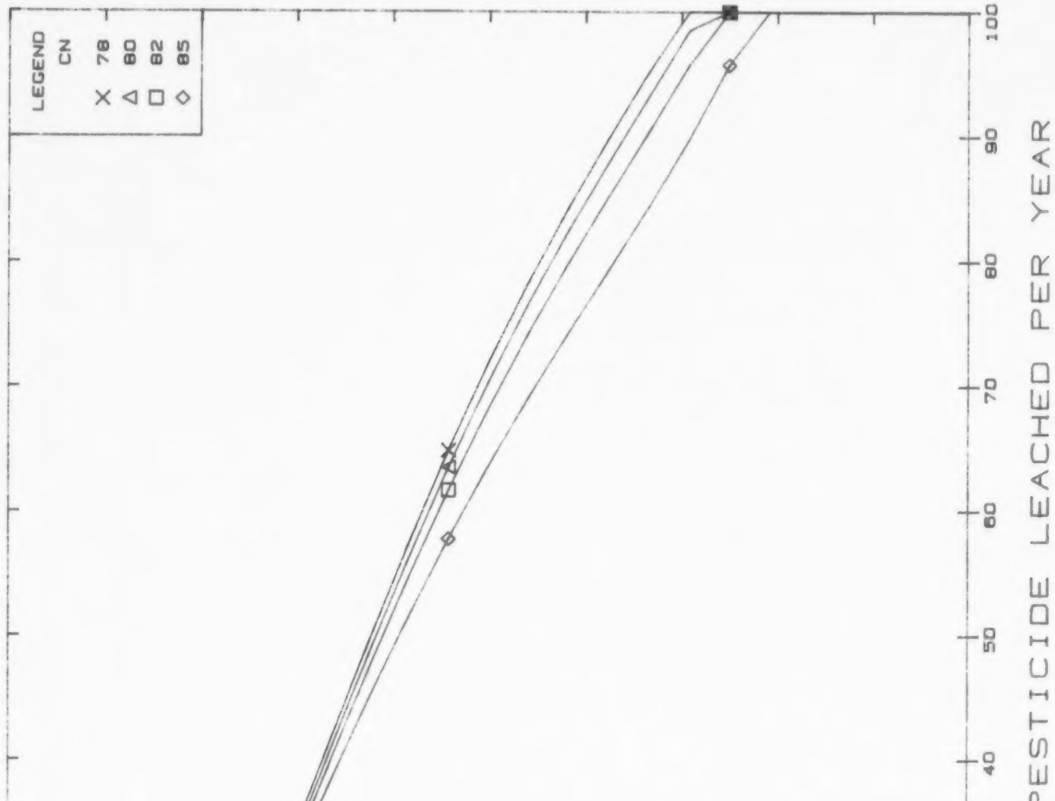


FIGURE A7-1 R=1. KS=.001

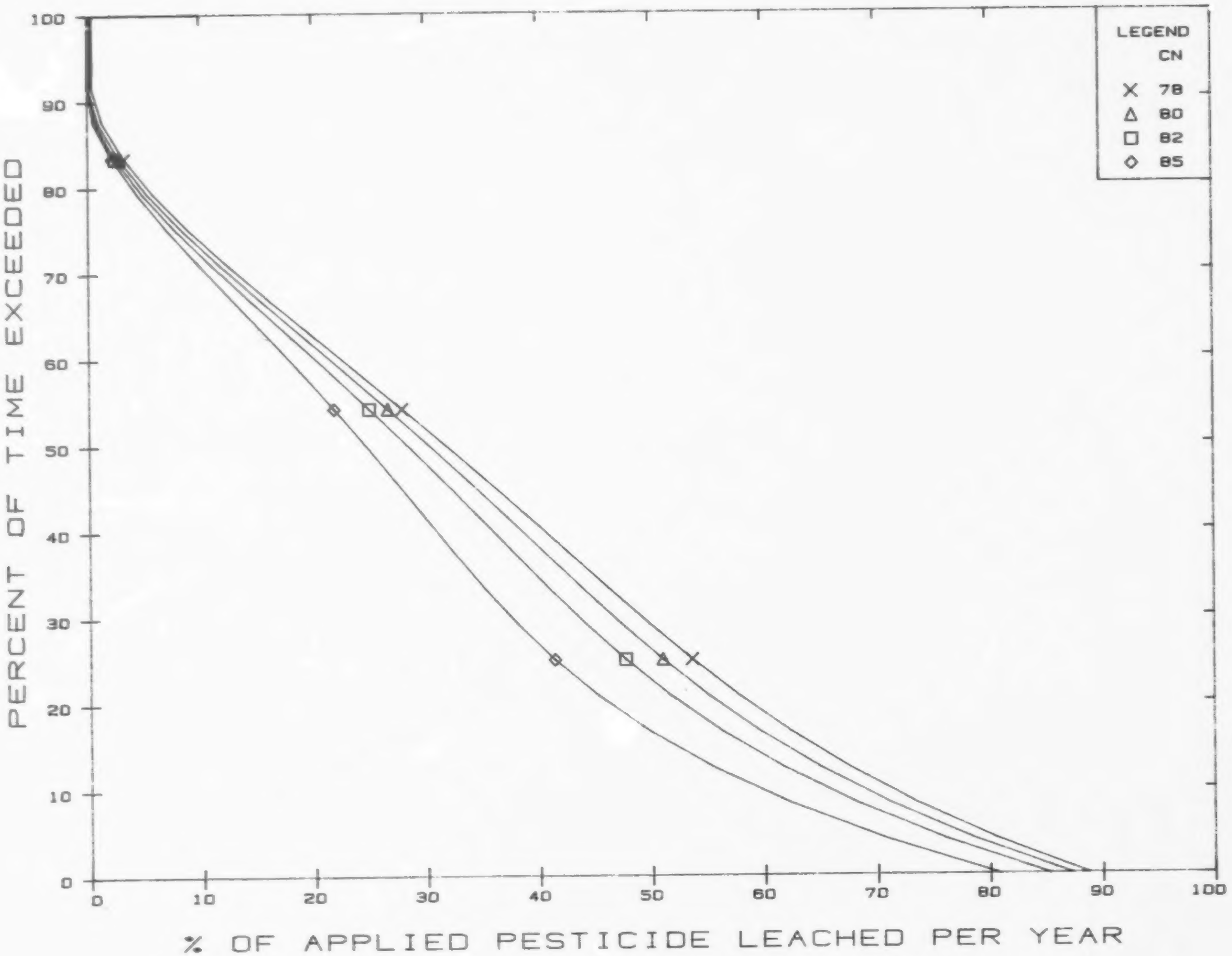


FIGURE A7-2 R=1. KS=.005

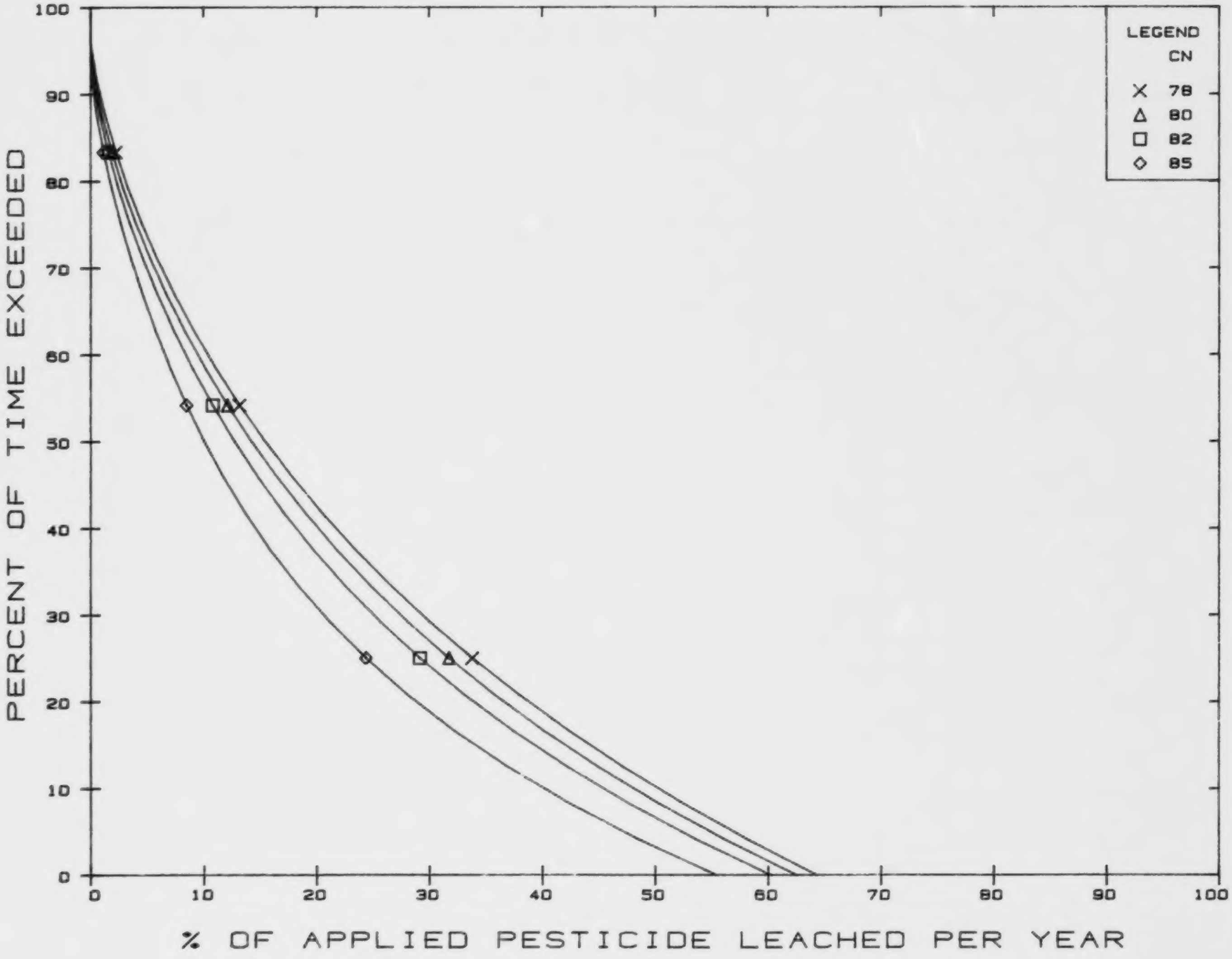


FIGURE A7-3 R=1. KS=.010

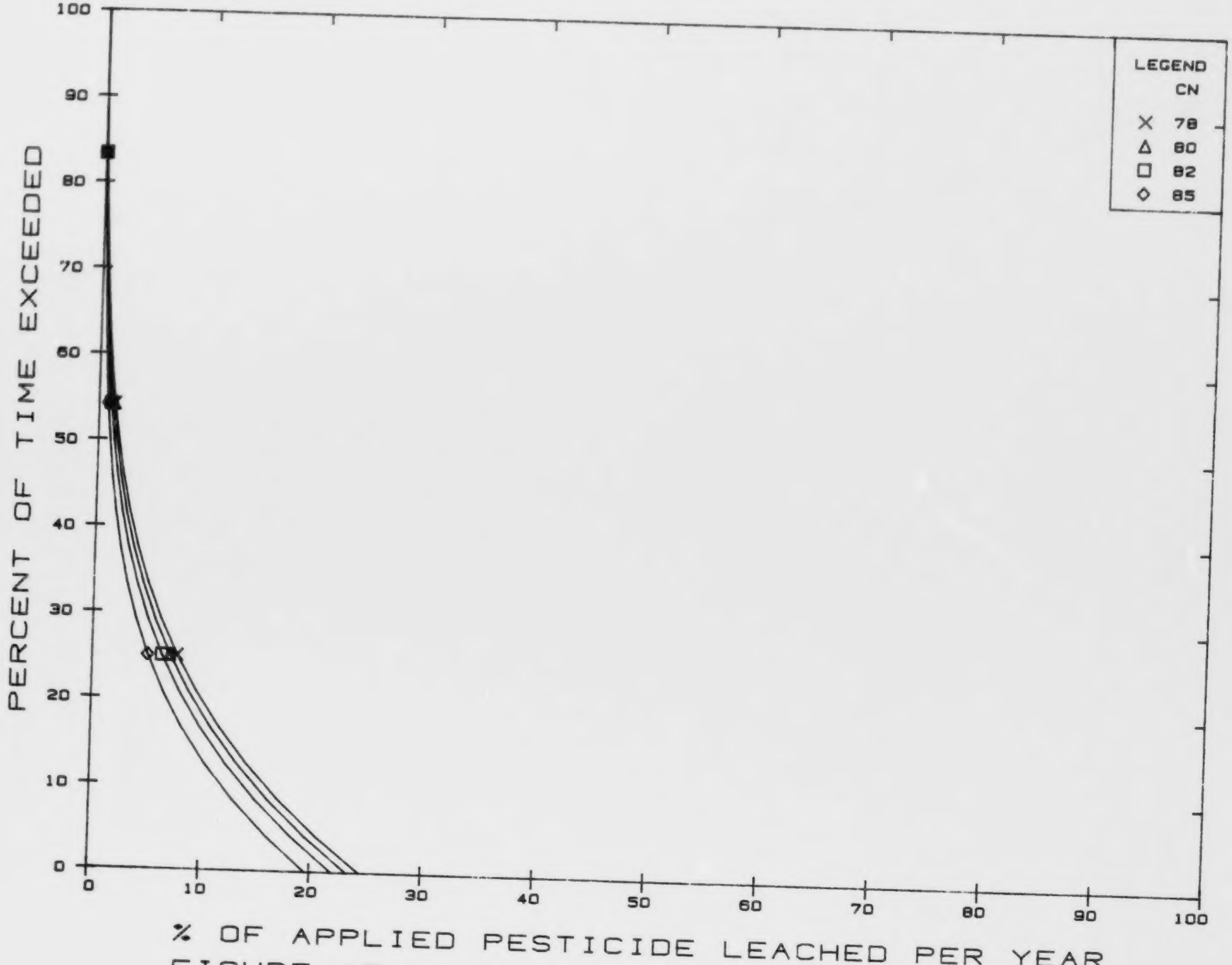


FIGURE A7-4 R=1. KS=.050

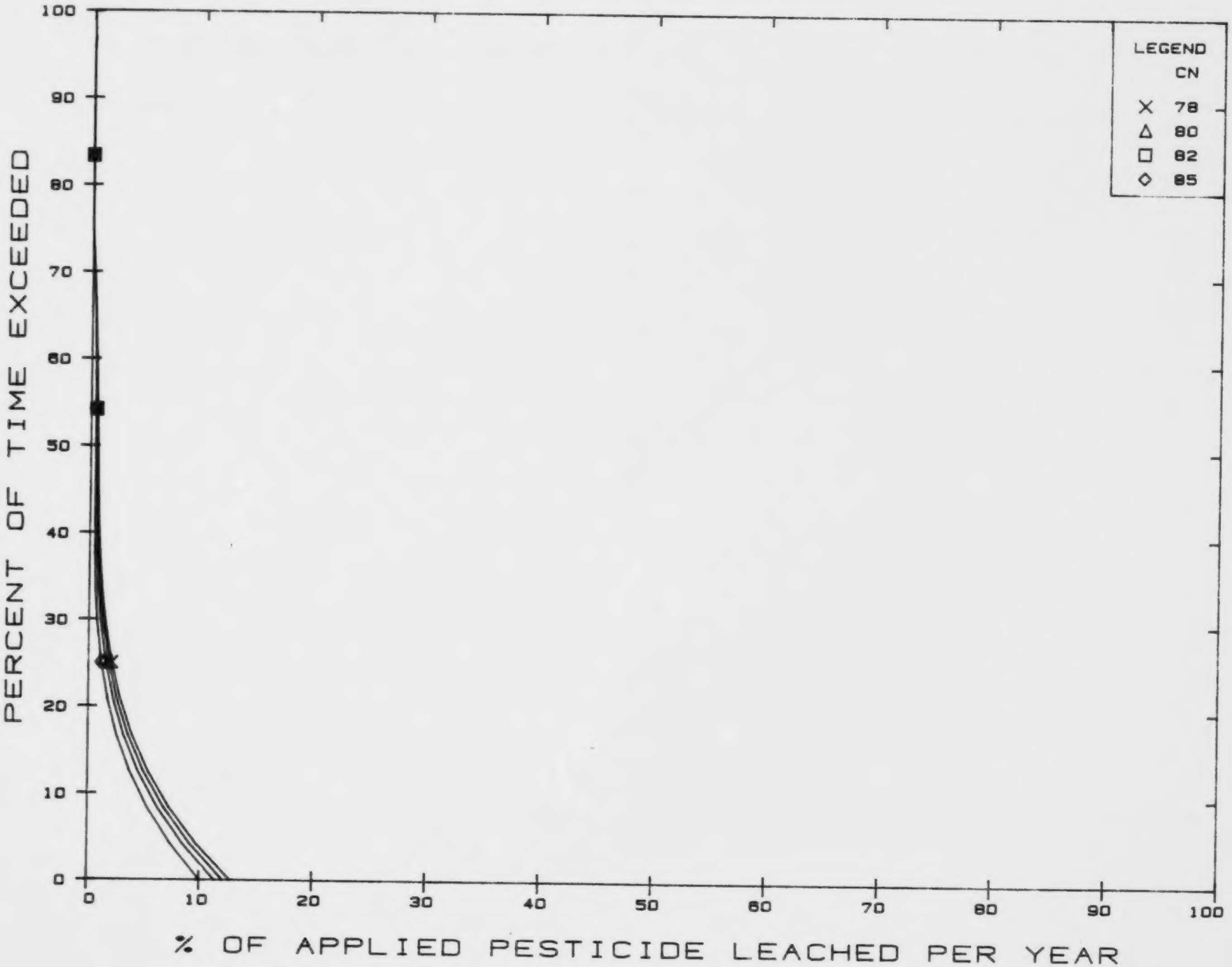


FIGURE A7-5 R=1. KS=.100

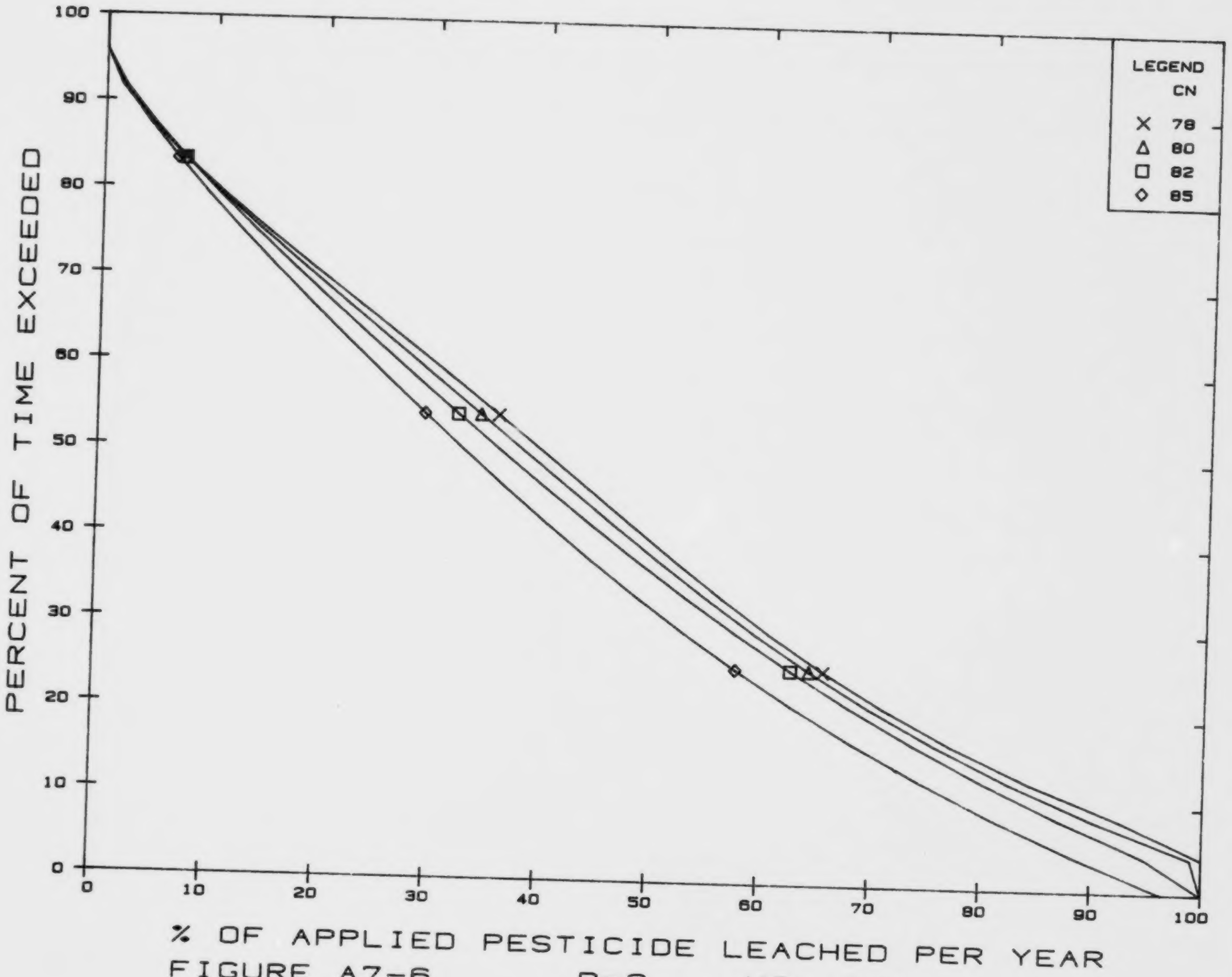


FIGURE A7-6 R=3. KS=.001

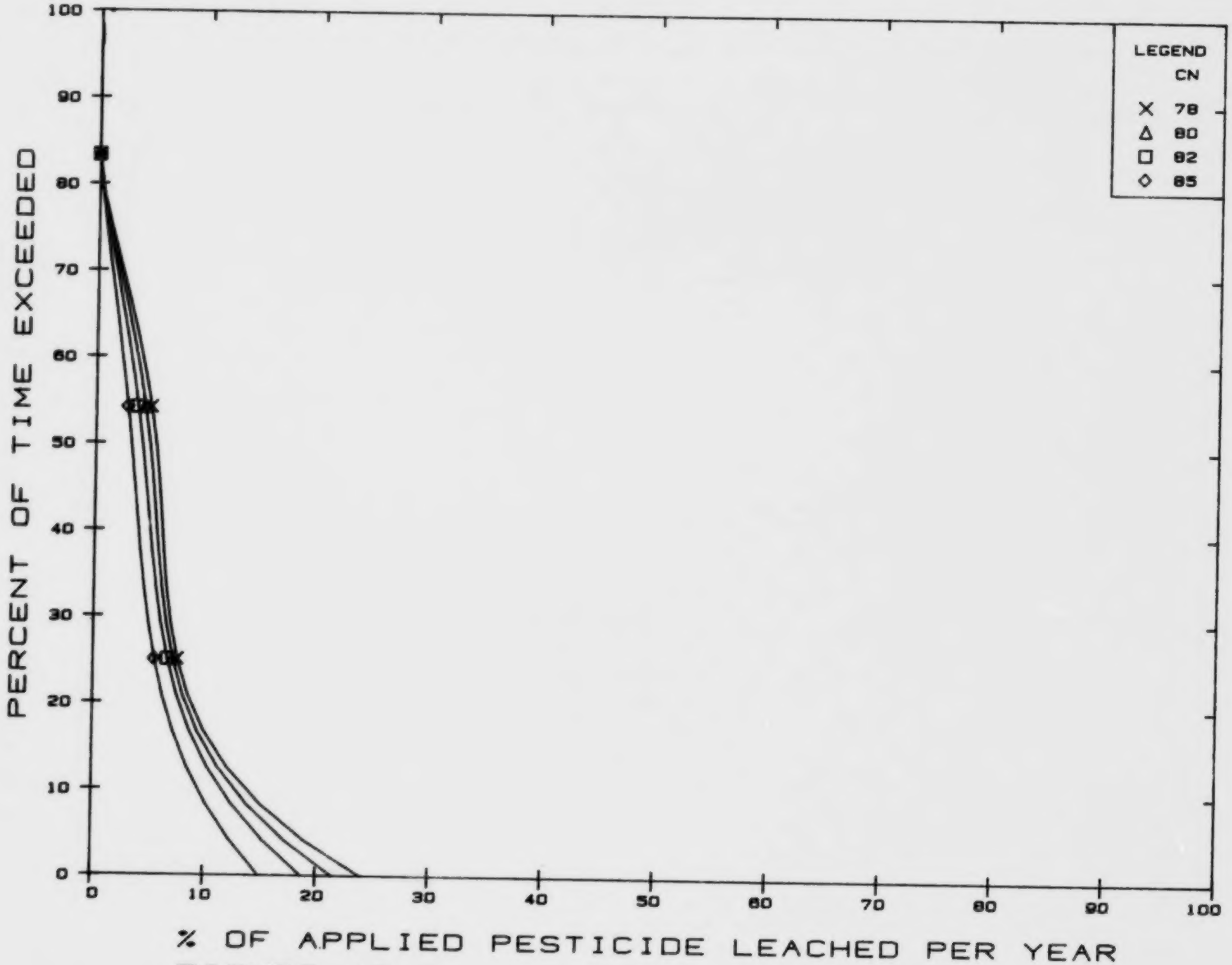


FIGURE A7-7 R=3. KS=.005

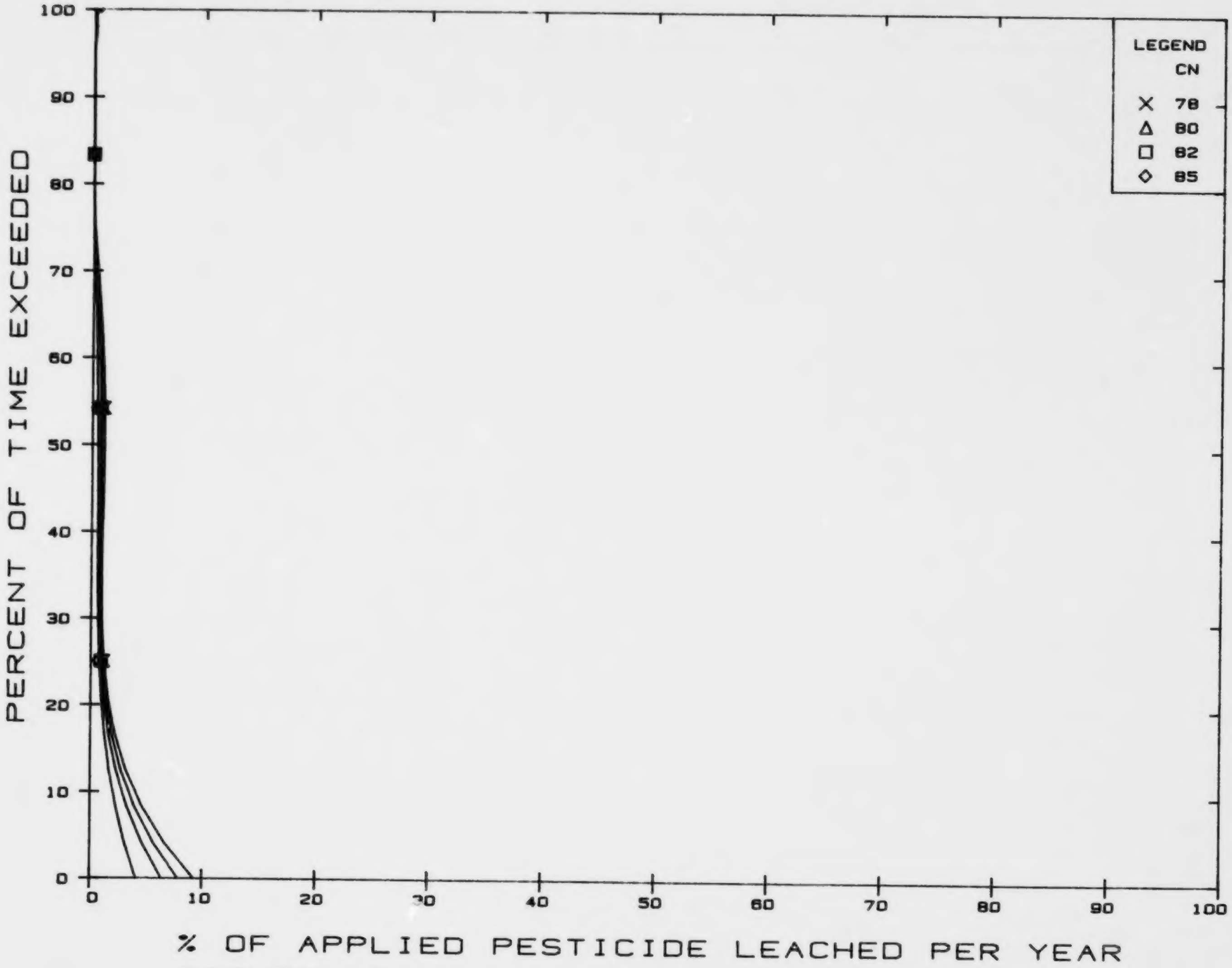


FIGURE A7-8 R=3. KS=.010

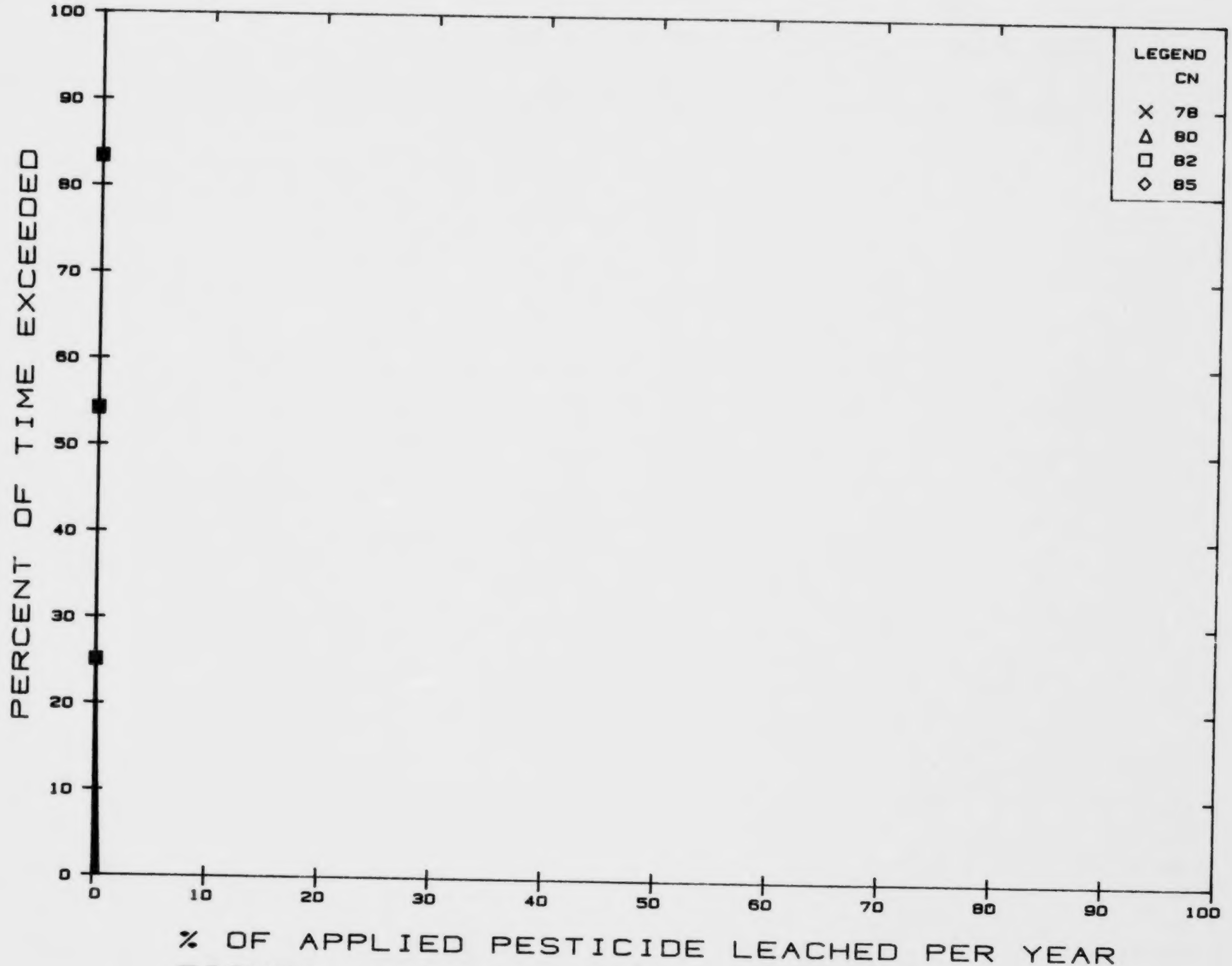


FIGURE A7-9 R=3. KS=.050

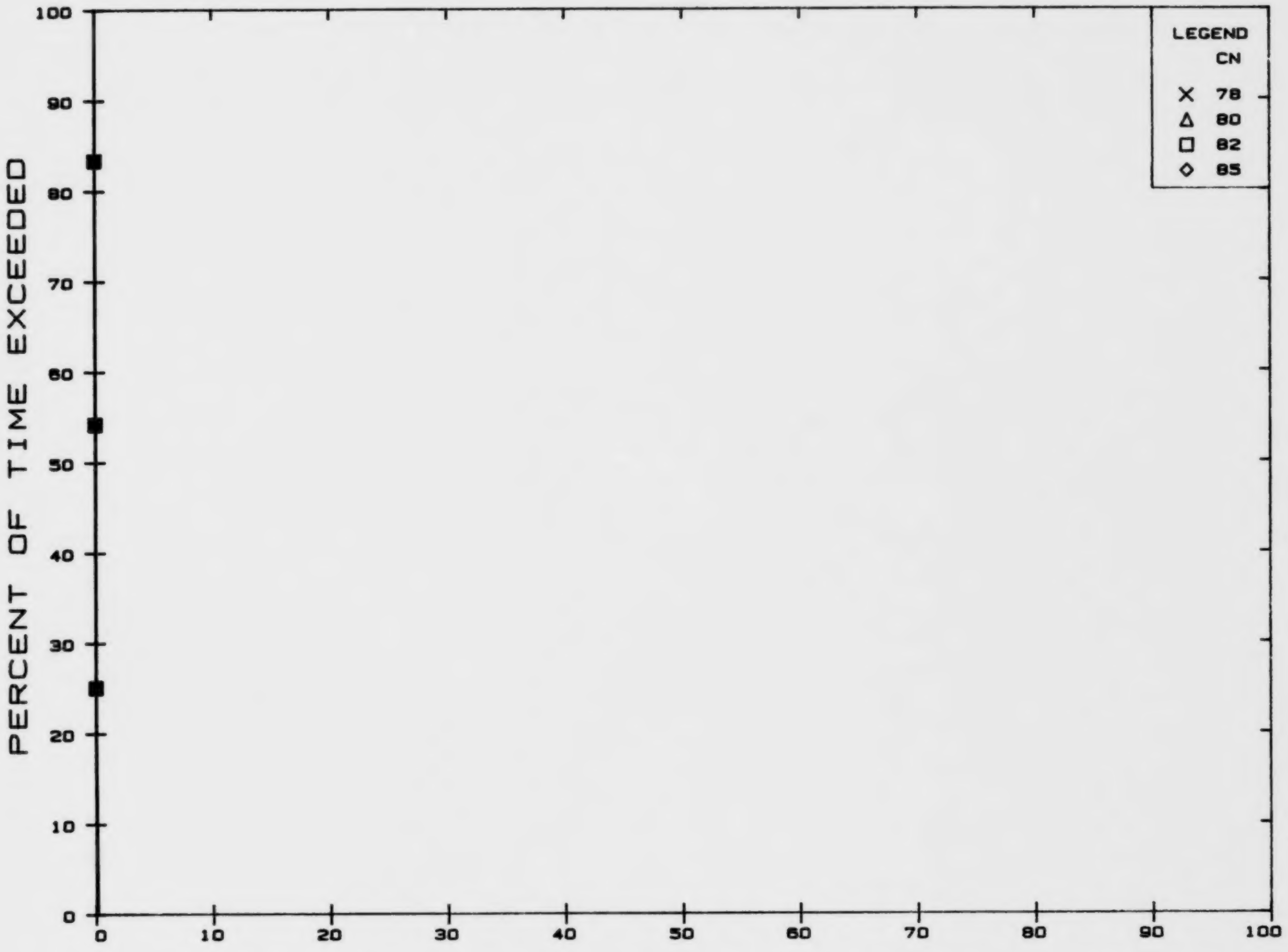


FIGURE A7-10 R=3. KS=.100

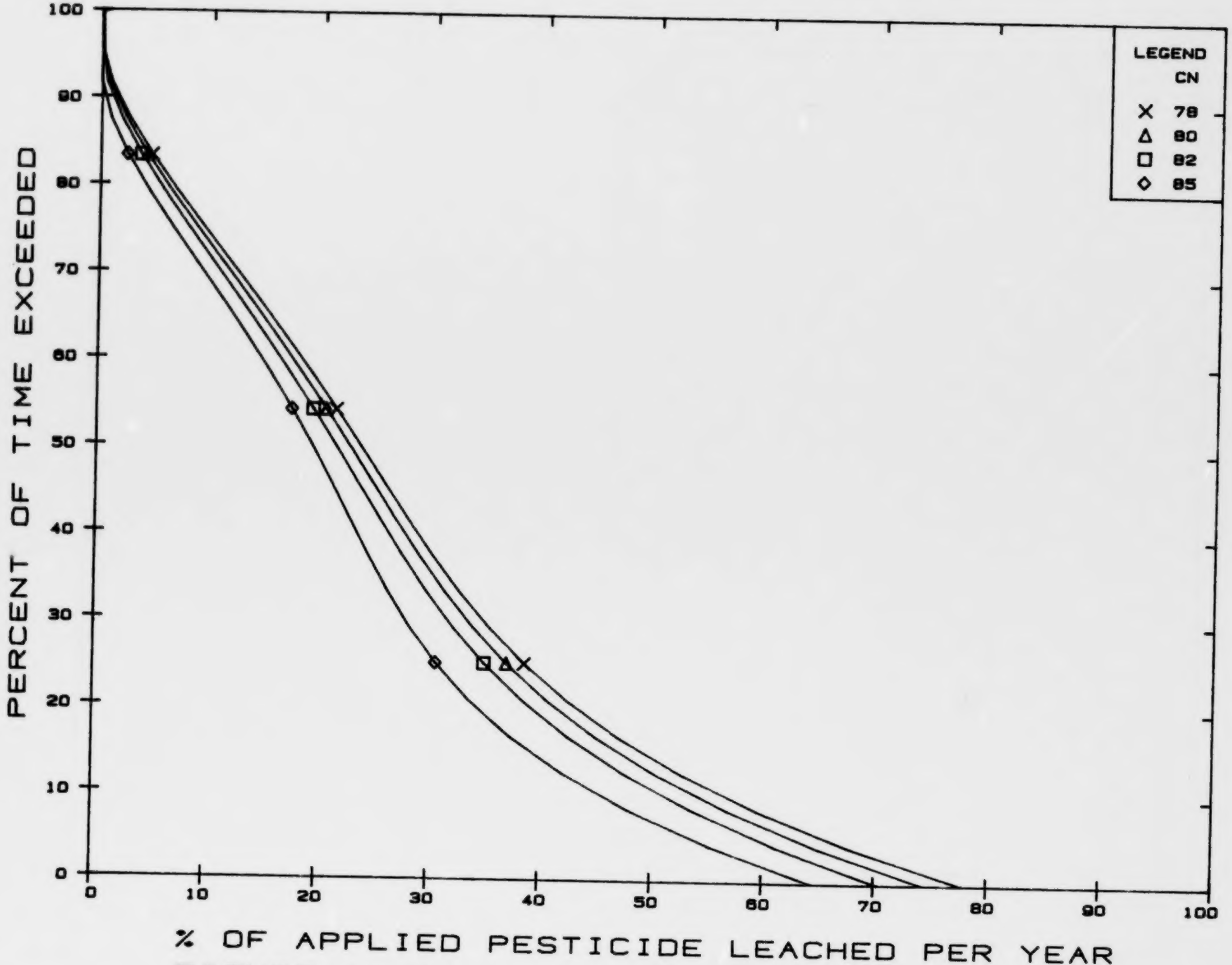


FIGURE A7-11 R=5. KS=.001

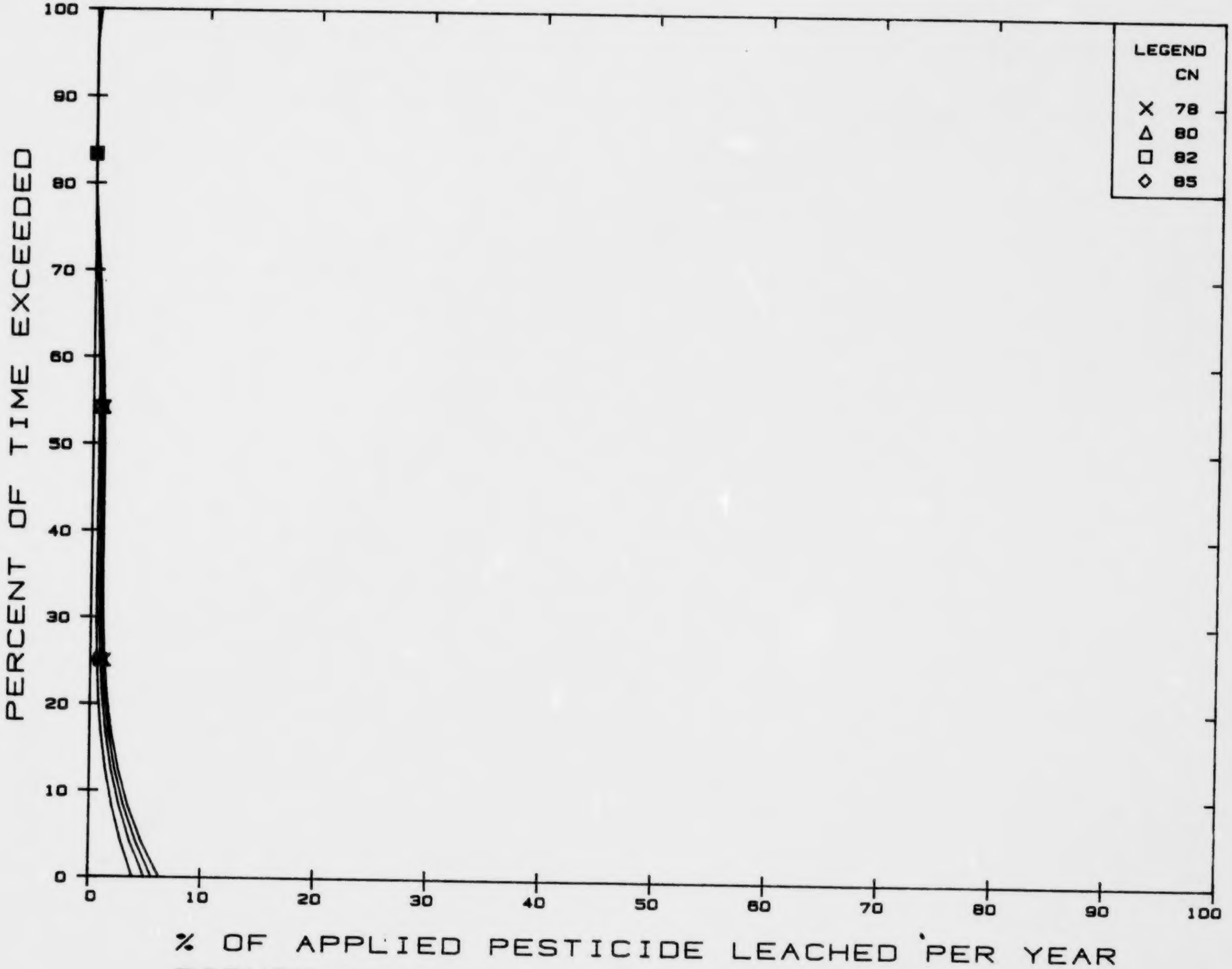


FIGURE A7-12 R=5. KS=.005

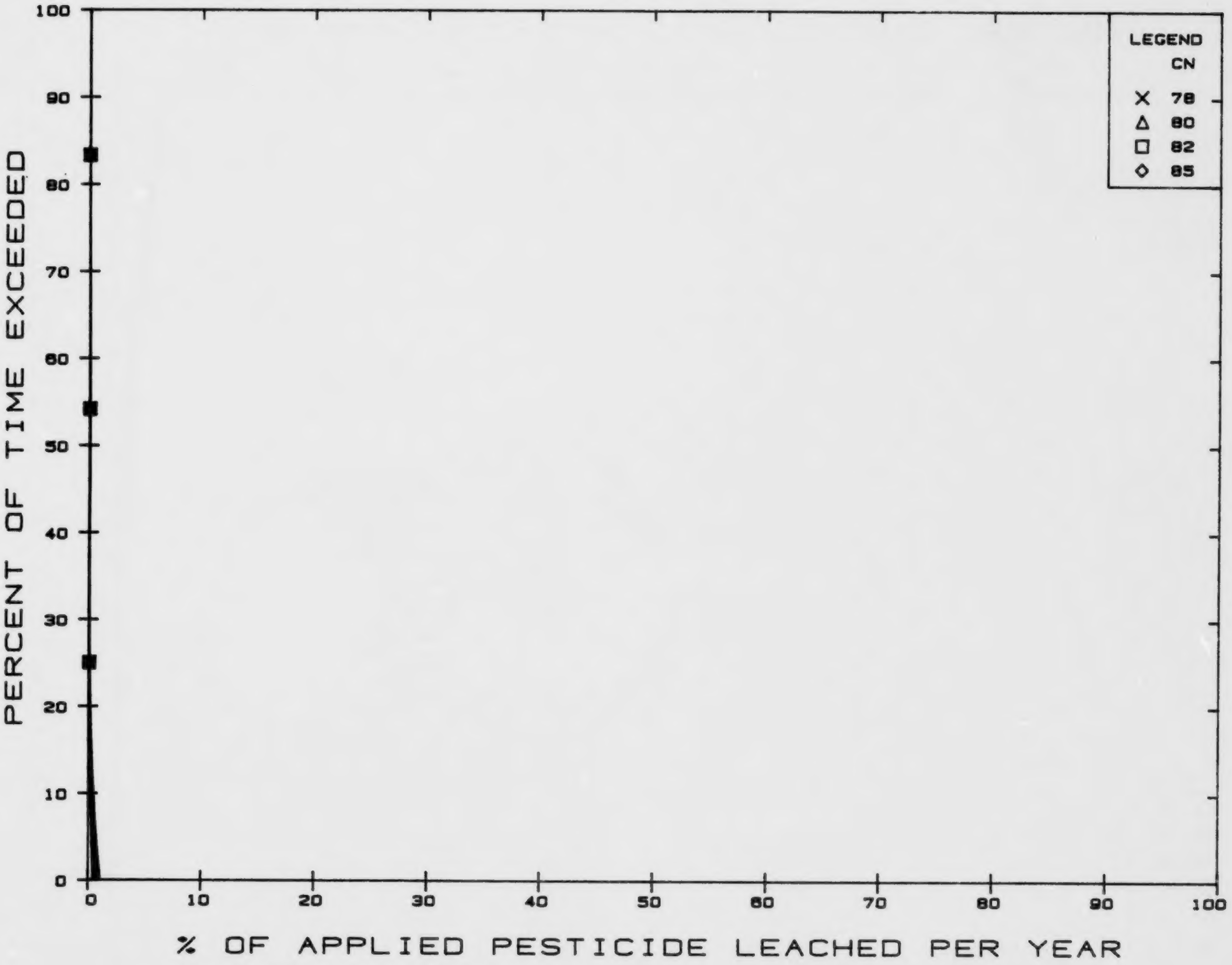


FIGURE A7-13 R=5. KS=.010

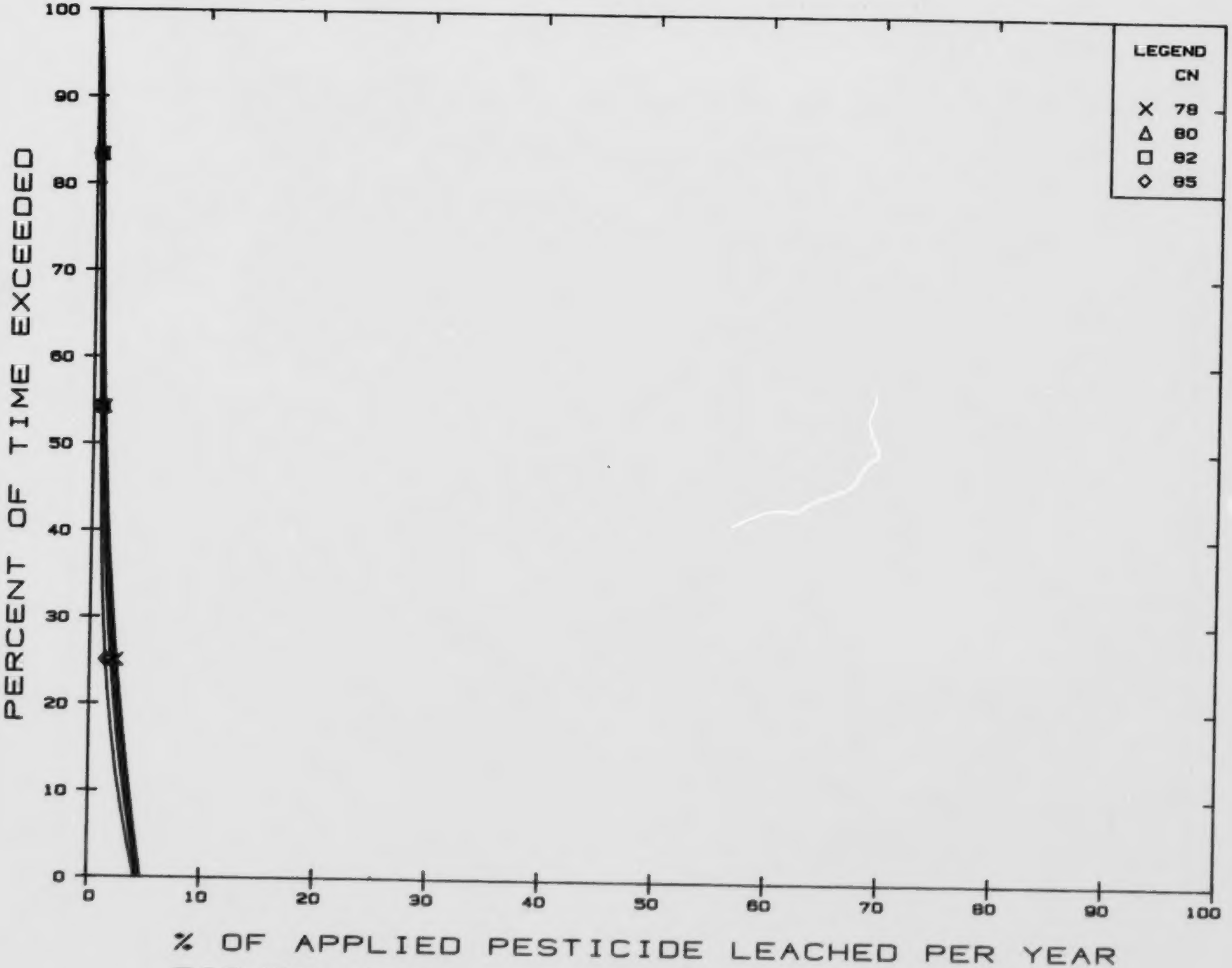


FIGURE A7-14 R=20. KS=.001

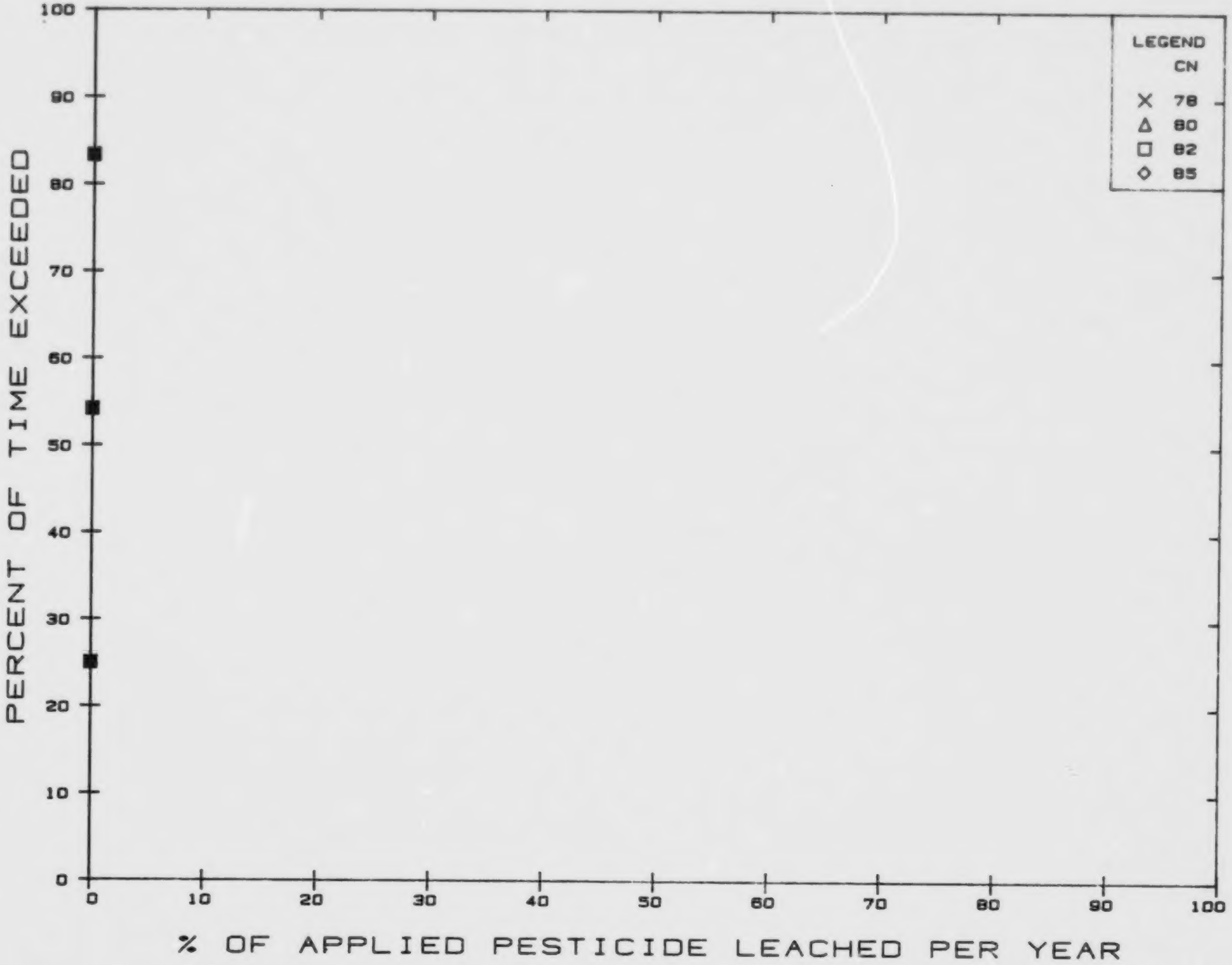


FIGURE A7-15 R=20. KS=.005

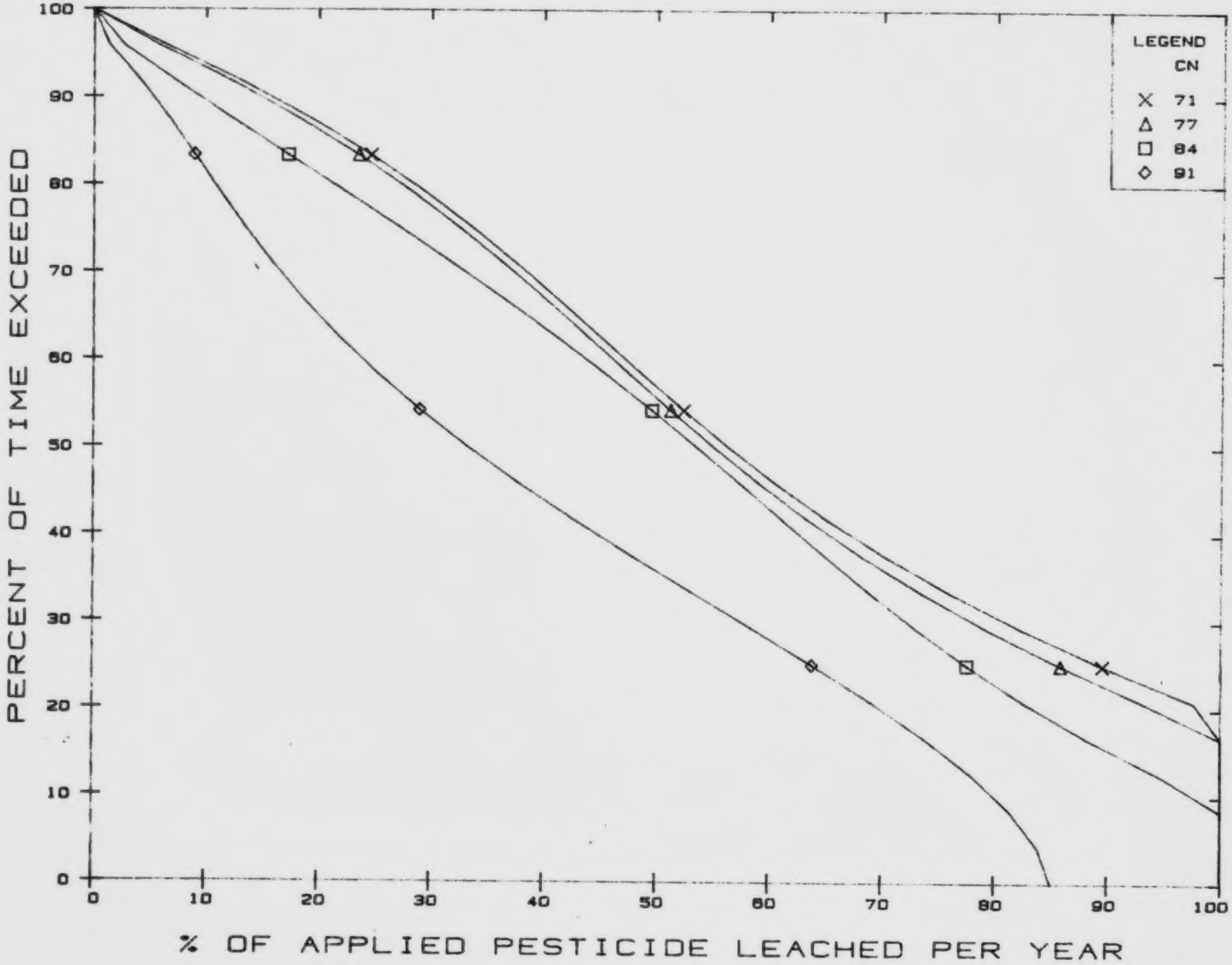


FIGURE A8-1 R=1. KS=.001

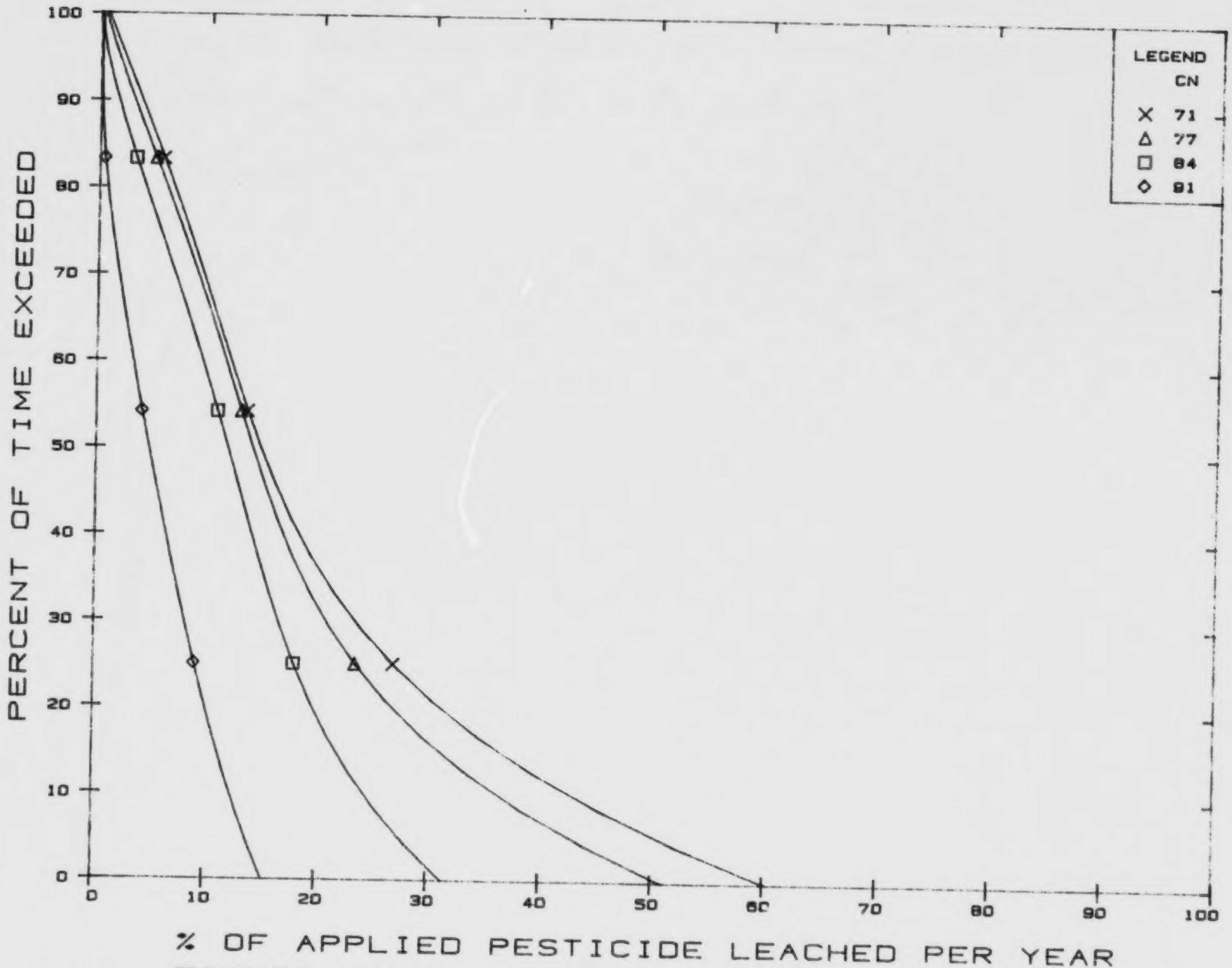


FIGURE A8-2 R=1. KS=.005

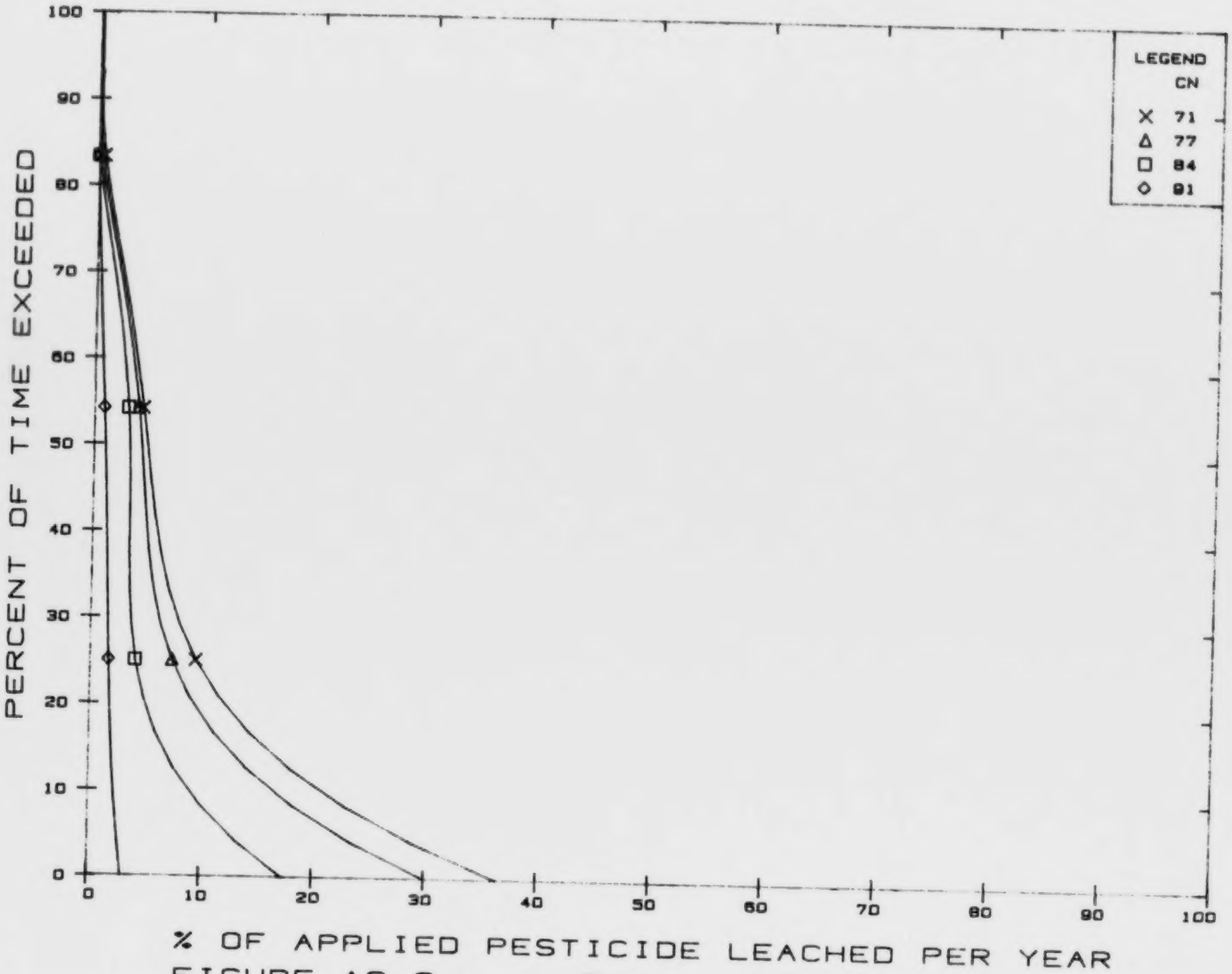
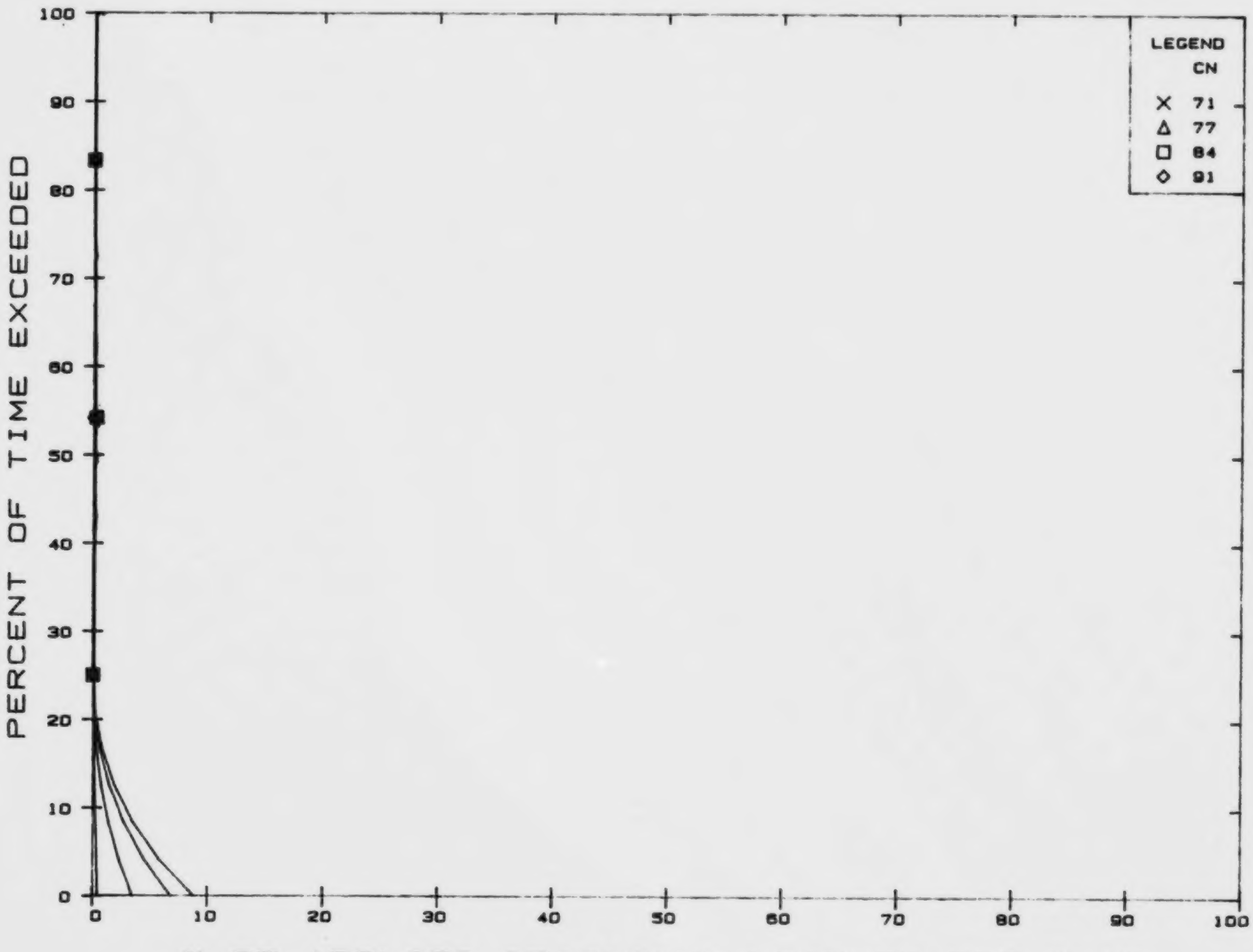


FIGURE A8-3 R=1. KS=.010



% OF APPLIED PESTICIDE LEACHED PER YEAR

FIGURE A8-4   R=1.   KS=.050

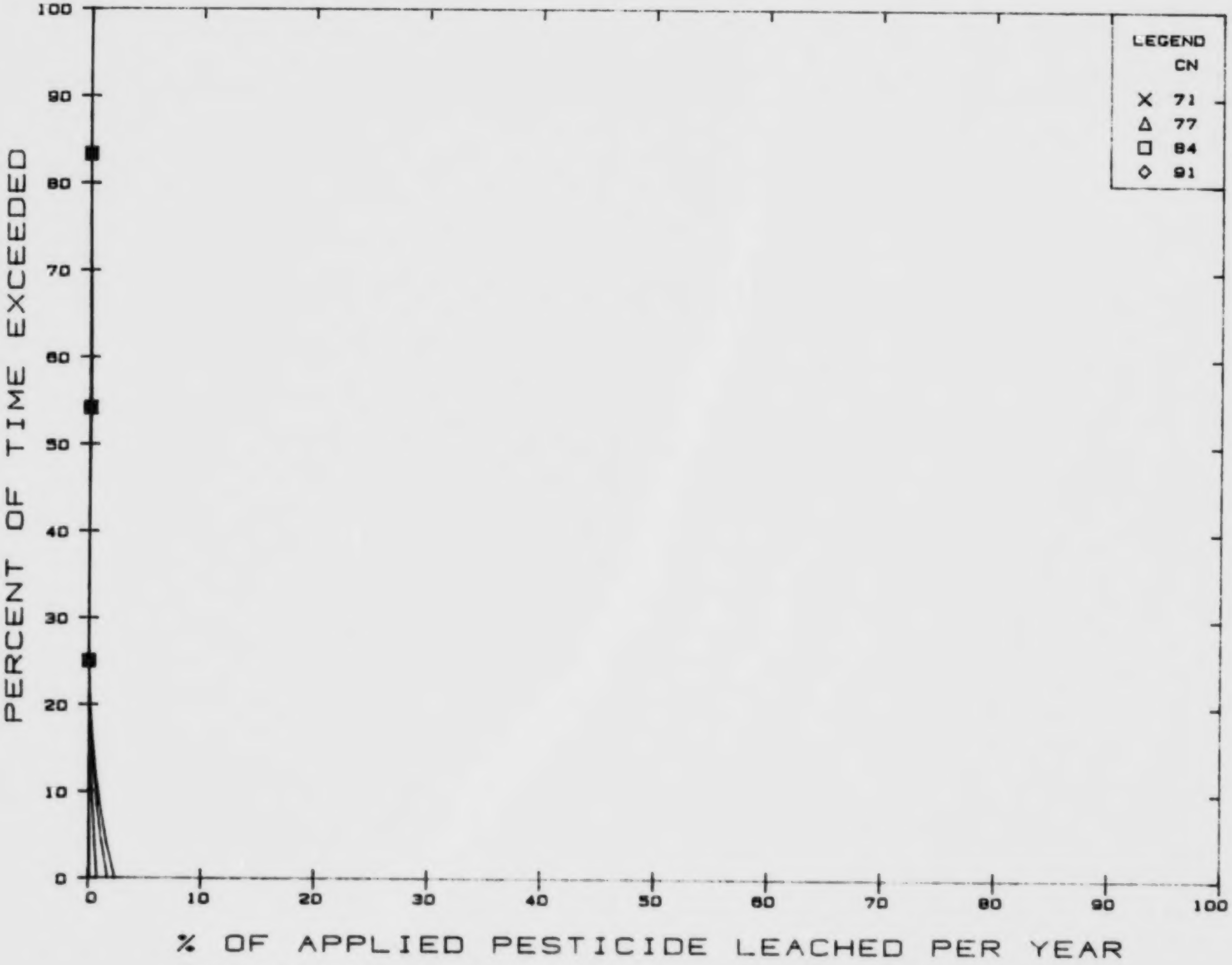


FIGURE A8-5 R=1. KS=.100

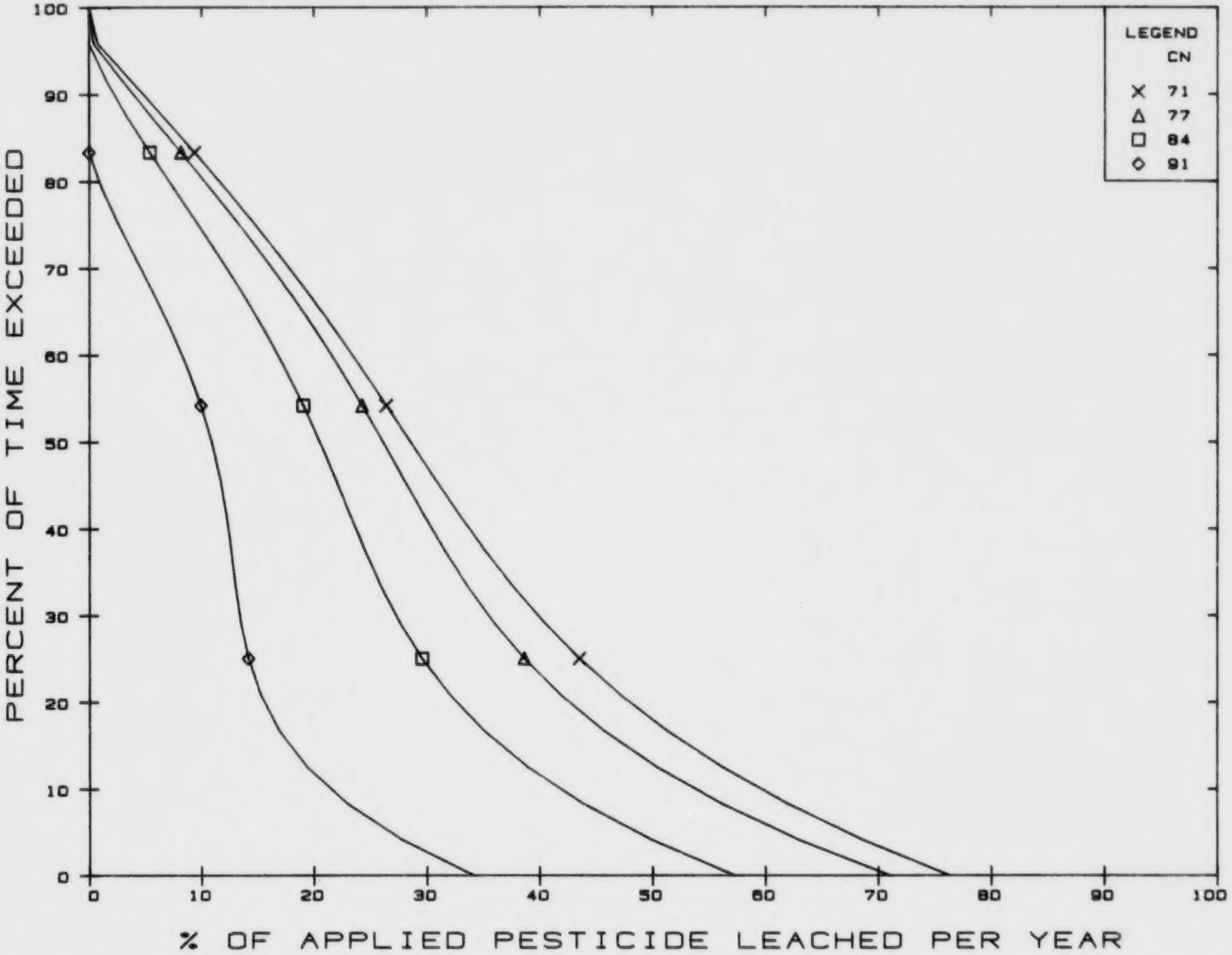


FIGURE A8-6 R=3. KS=.001

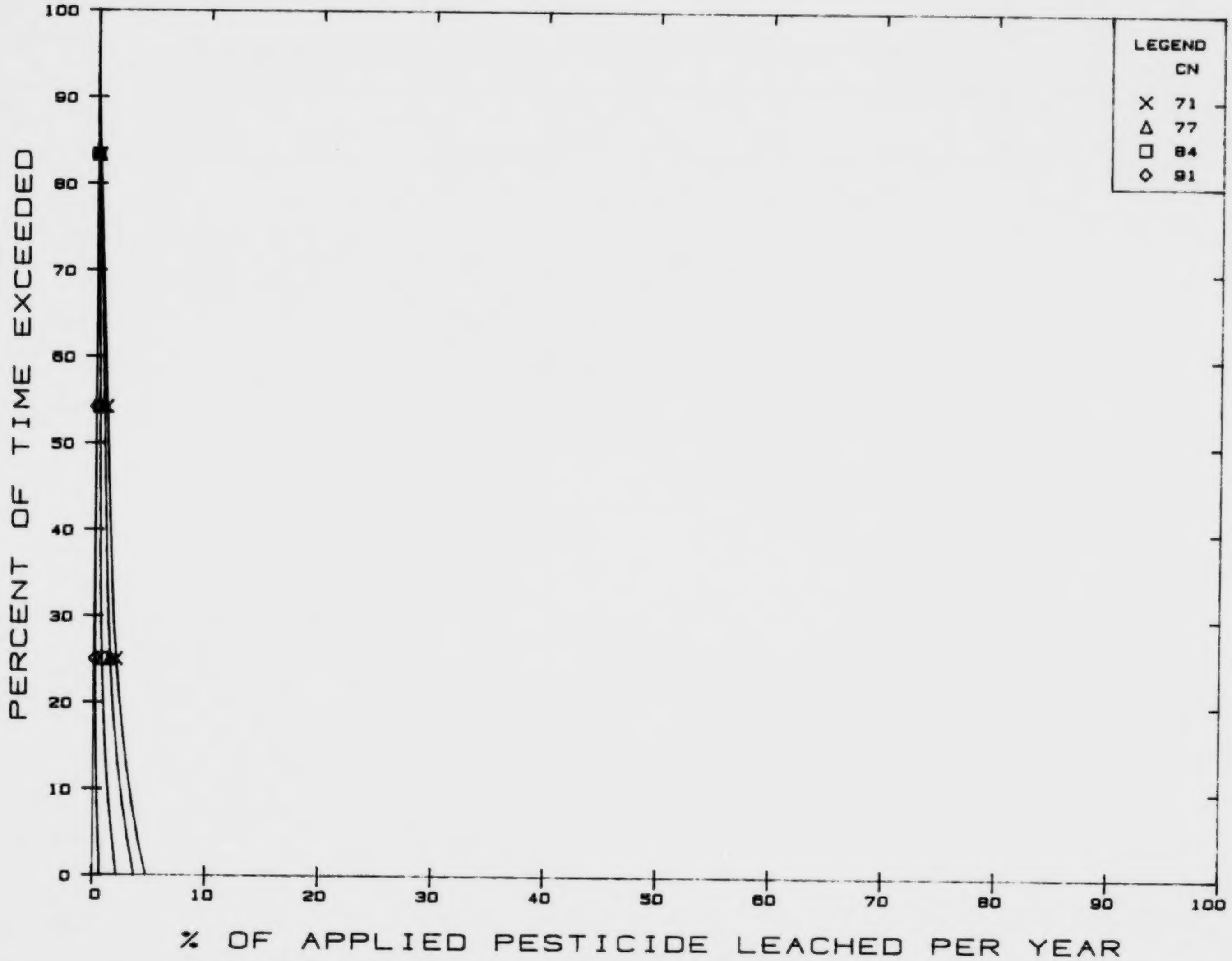


FIGURE A8-7 R=3. KS=.005

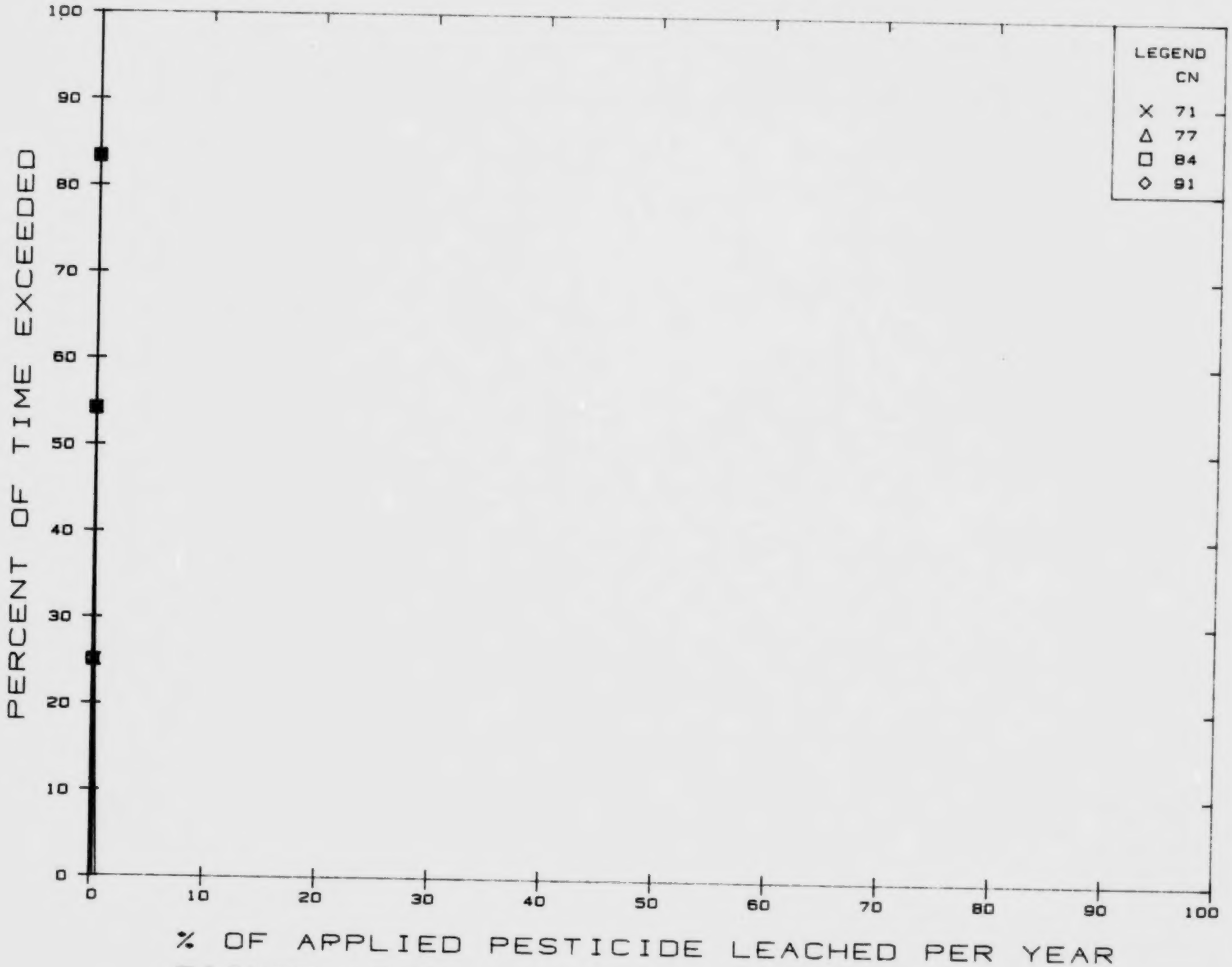


FIGURE A8-8 R=3. KS=.010

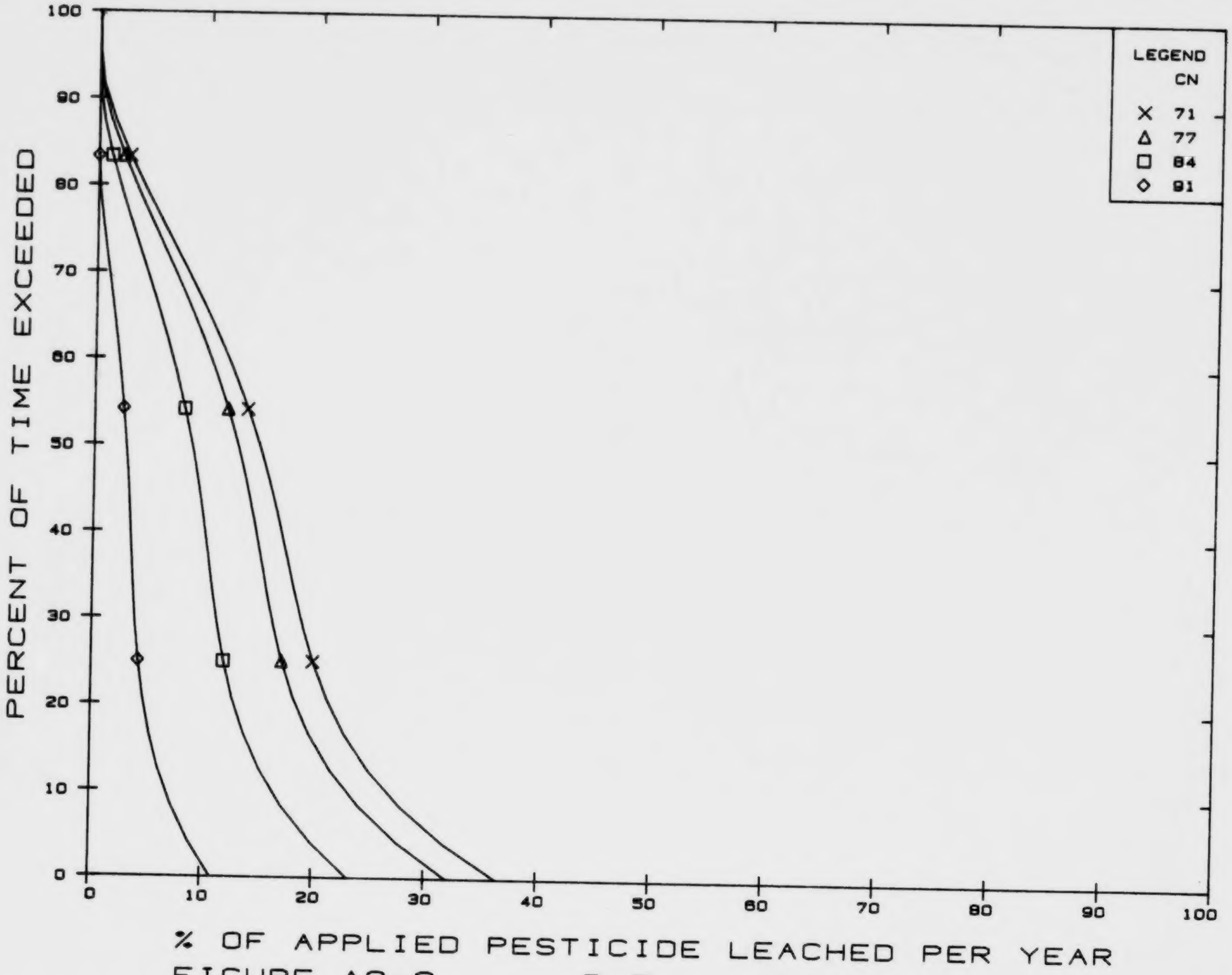


FIGURE A8-9 R=5. KS=.001

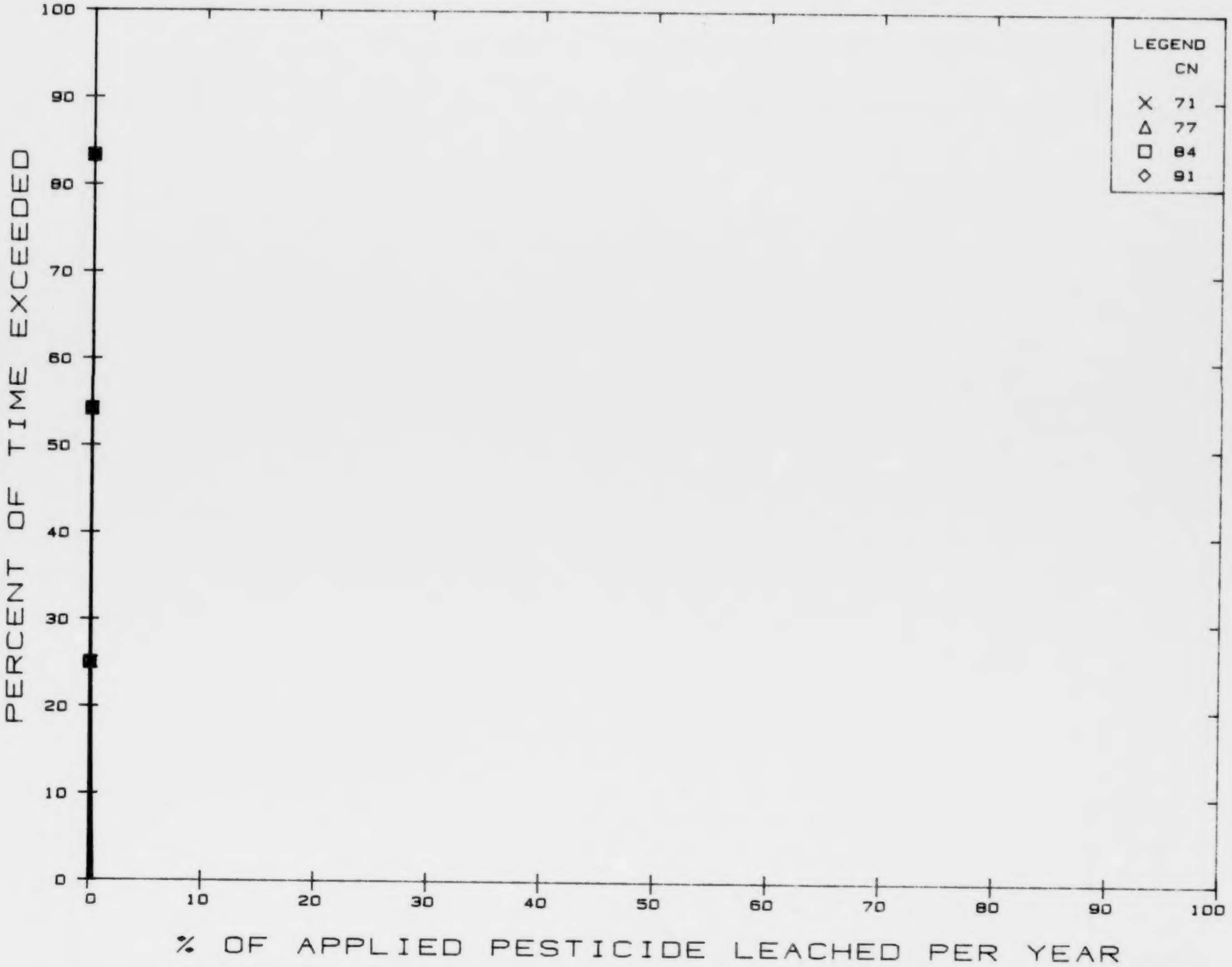


FIGURE A8-10 R=5. KS=.005

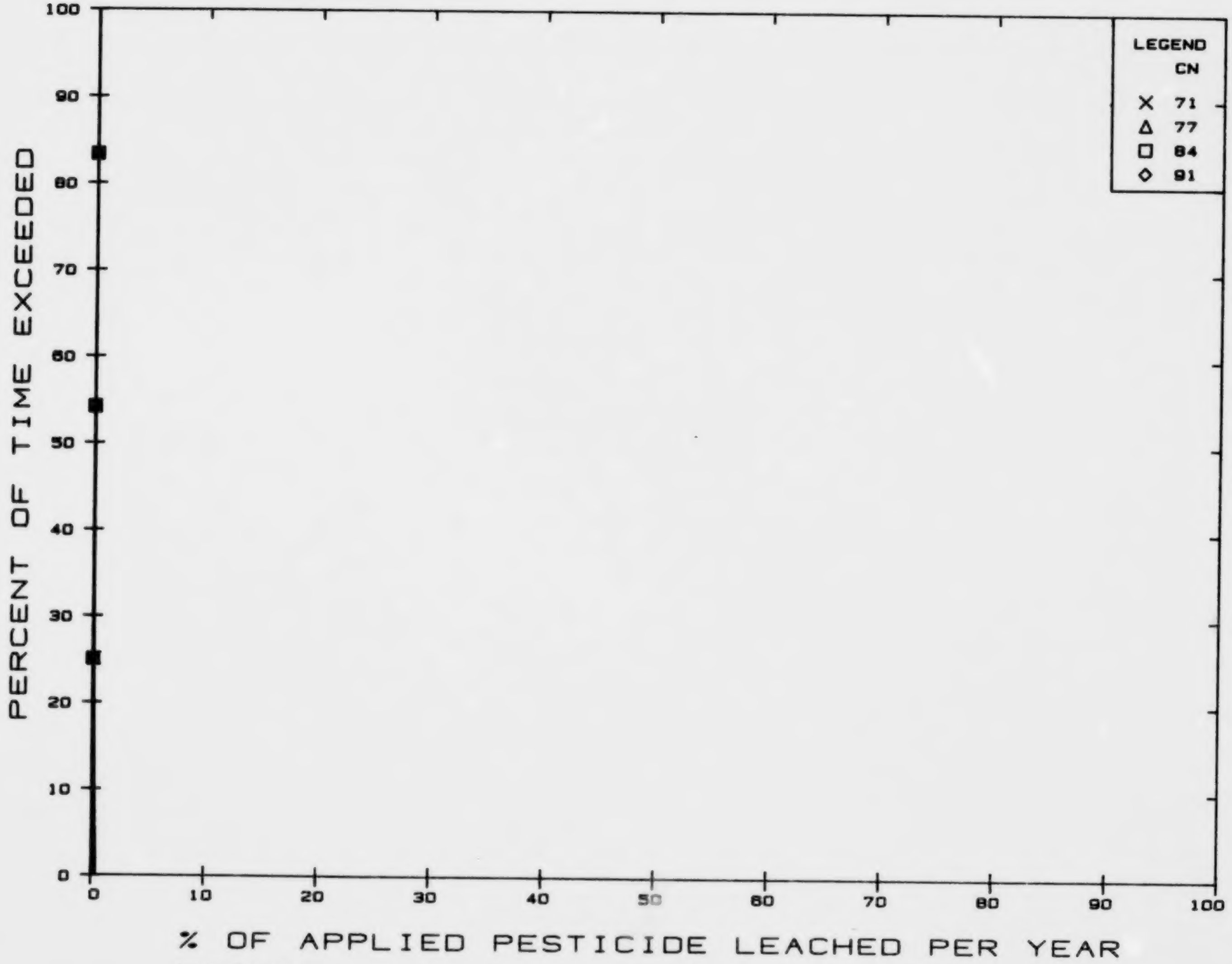


FIGURE A8-11 R=20. KS=.001

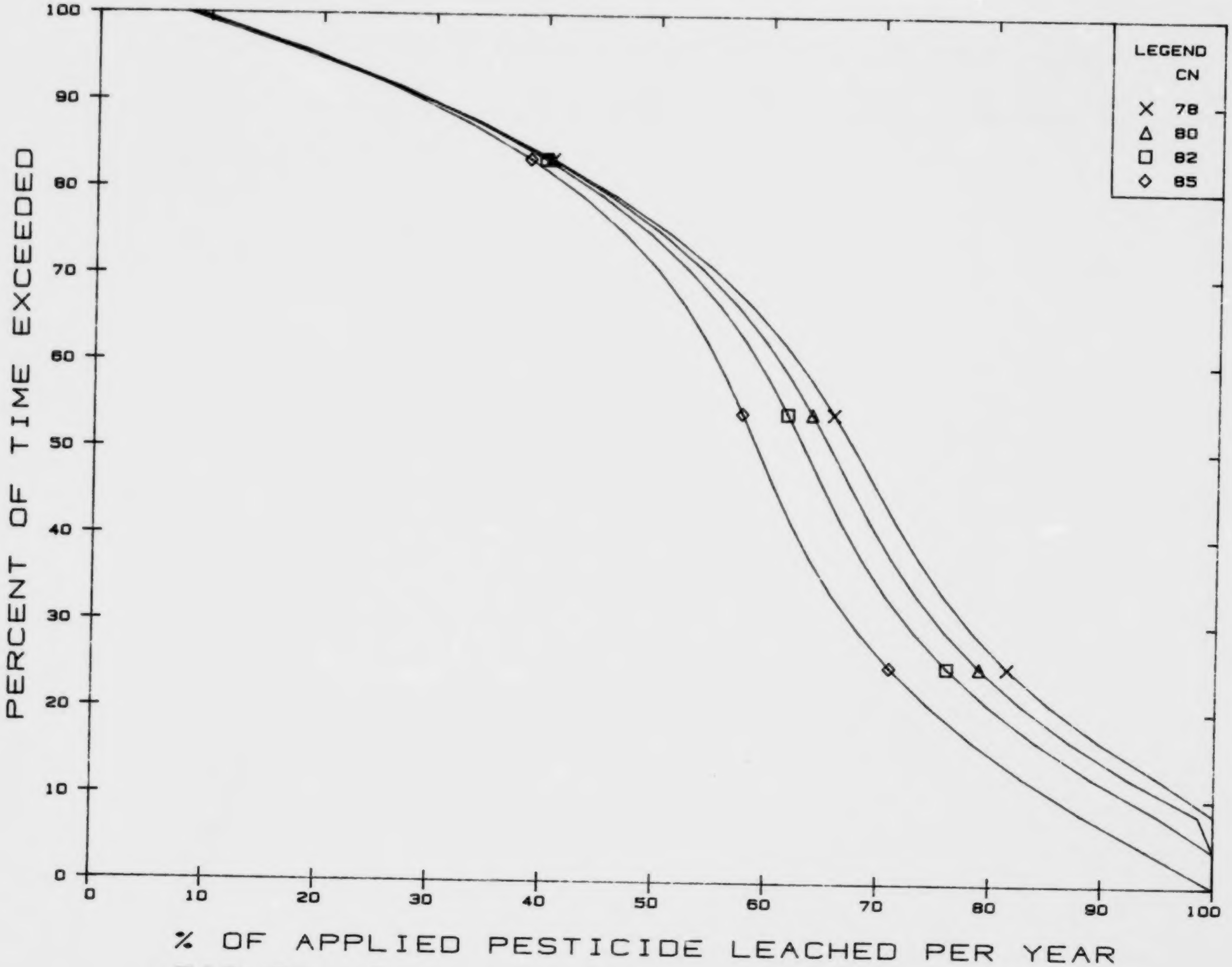


FIGURE A9-1 R=1. KS=.001

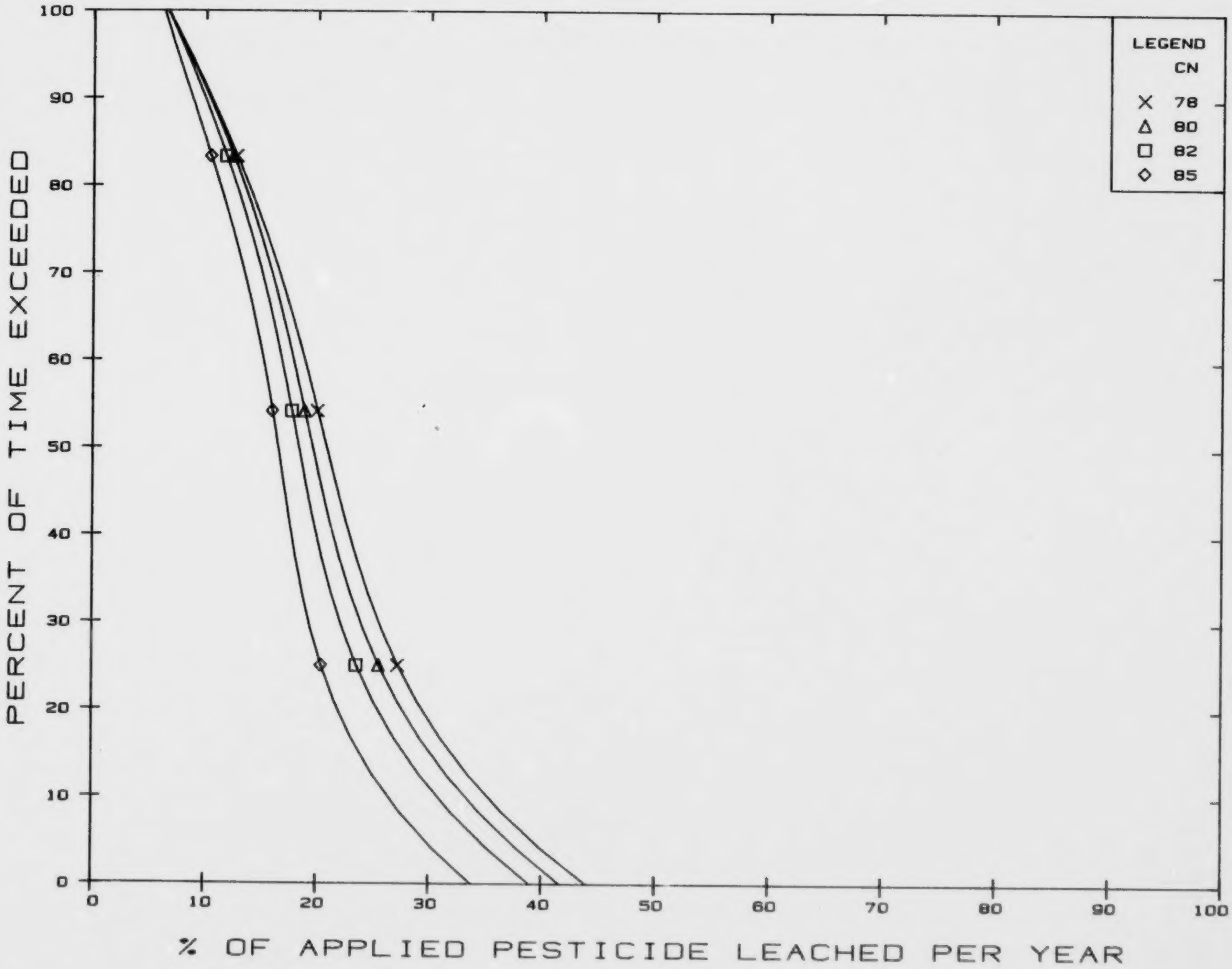


FIGURE A9-2 R=1. KS=.005

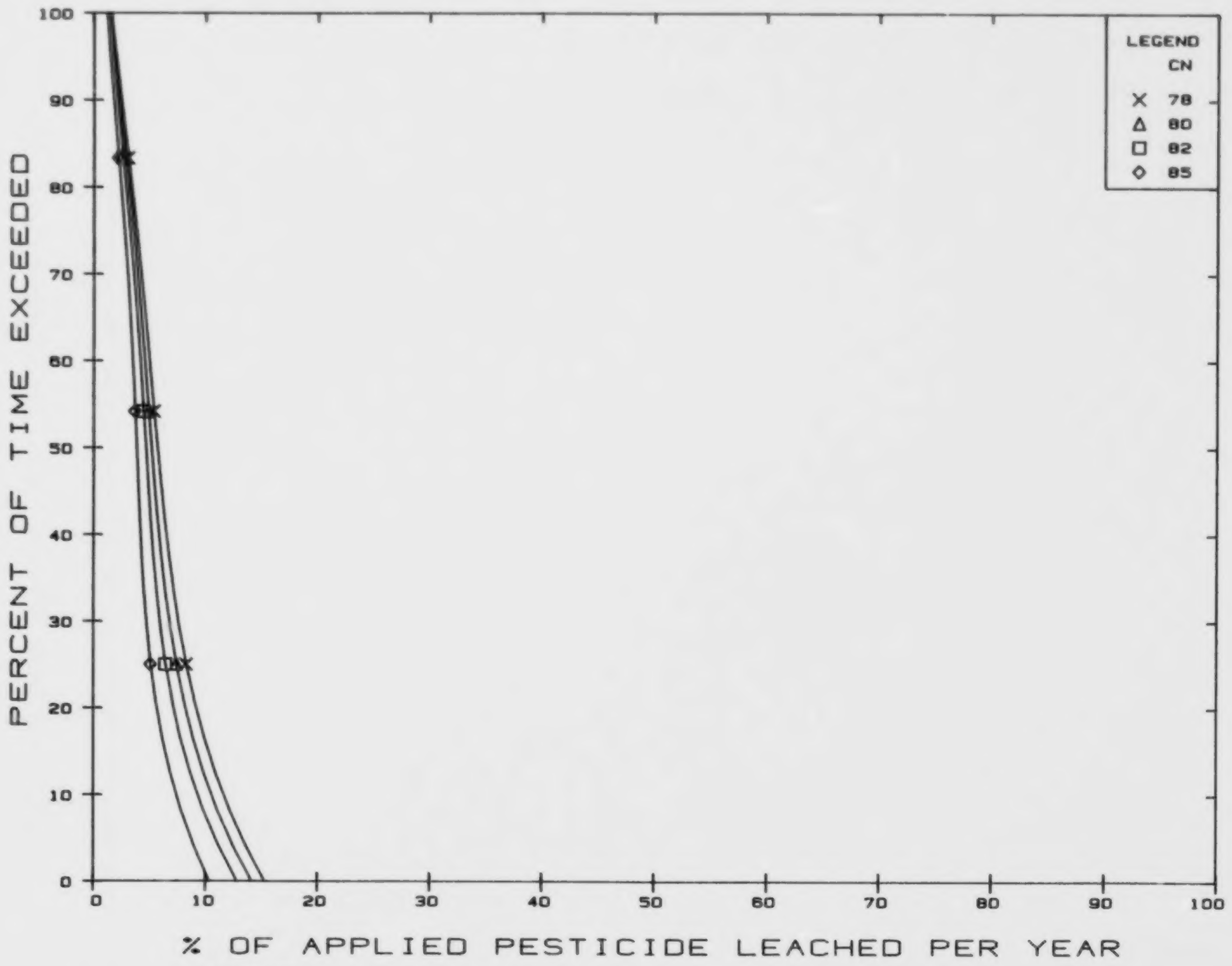


FIGURE A9-3 R=1. KS=.010

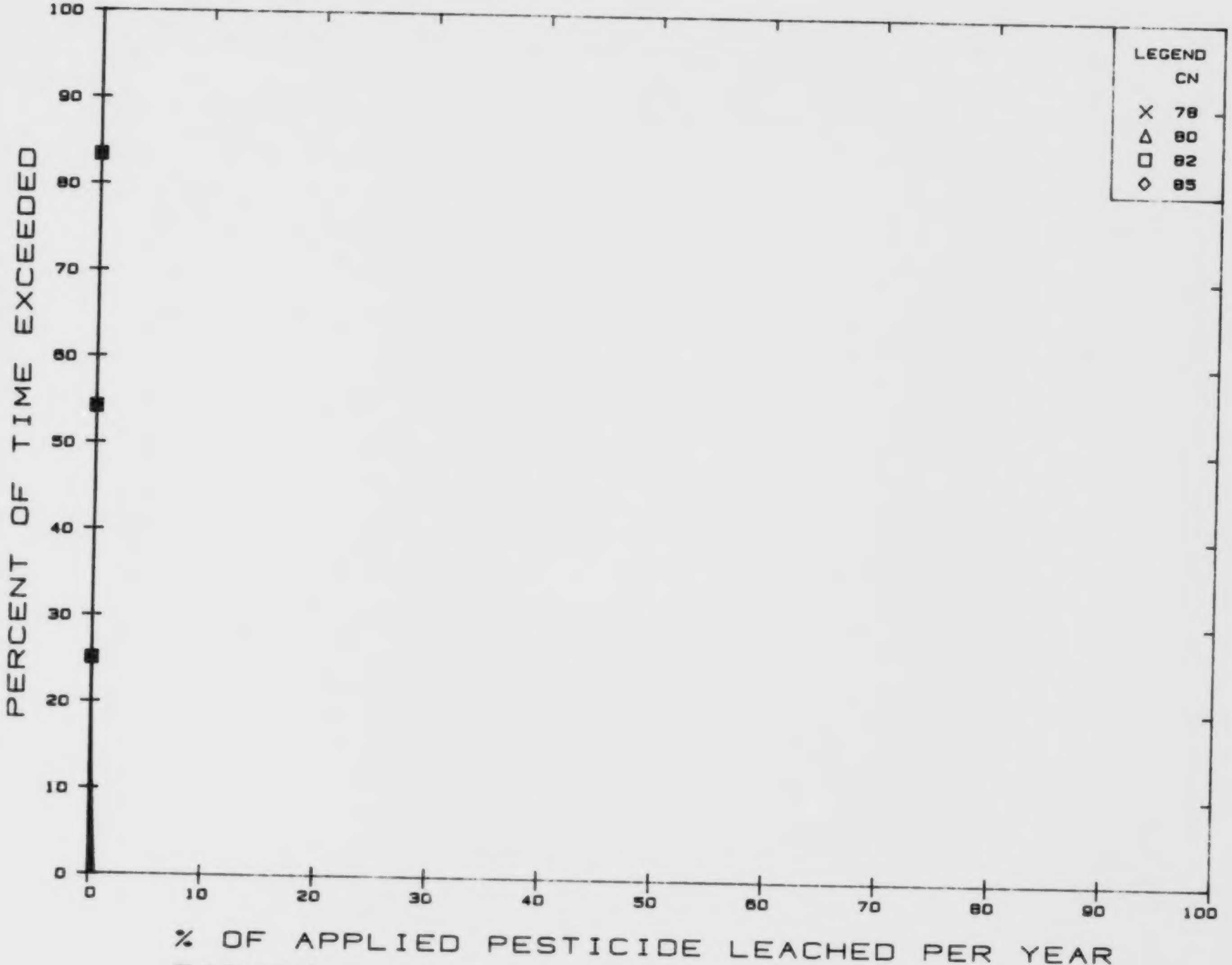


FIGURE A9-4 R=1. KS=.050

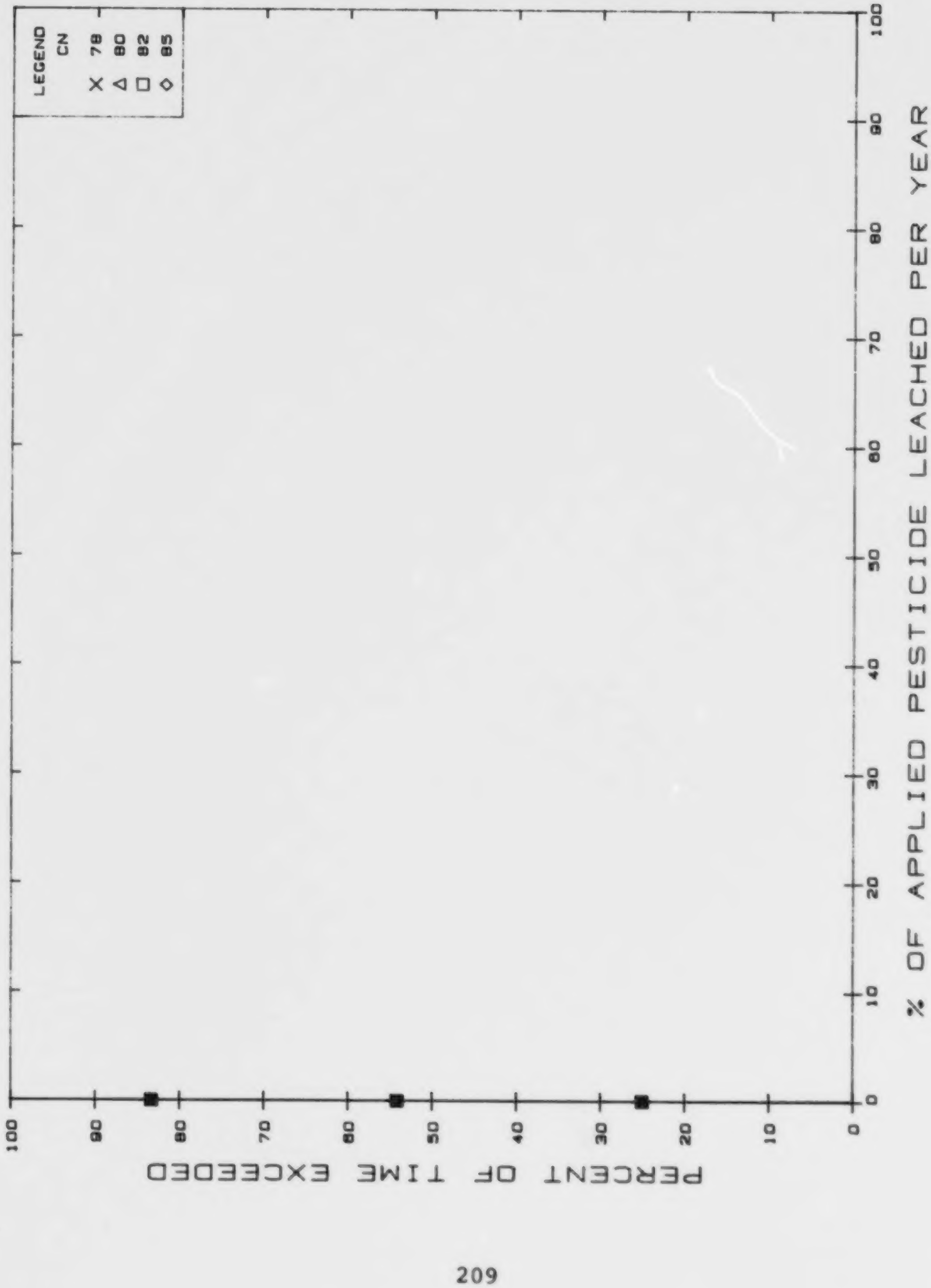


FIGURE AS-5 R=1. KS=.100

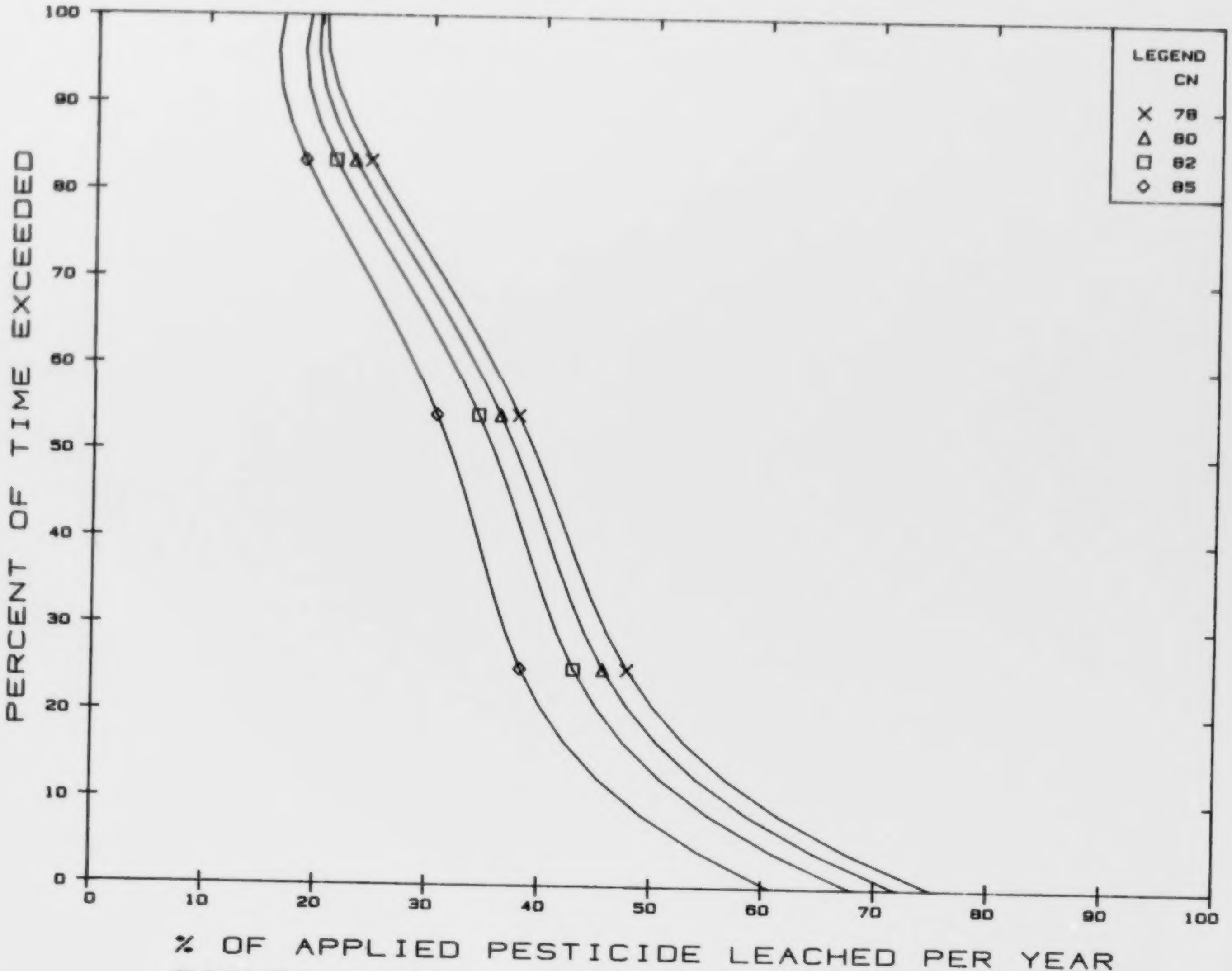


FIGURE A9-6 R=3. KS=.001

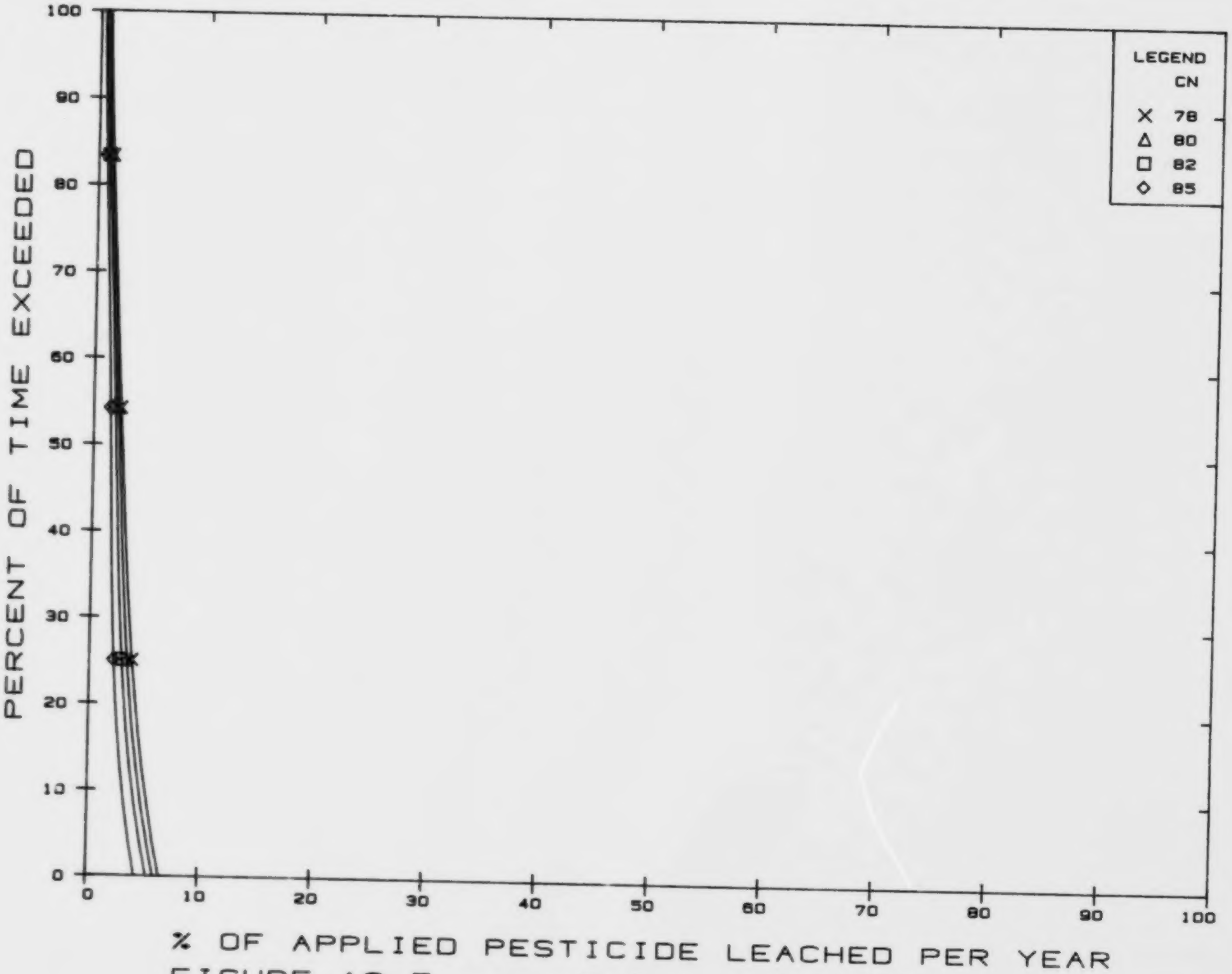


FIGURE A9-7 R=3. KS=.005

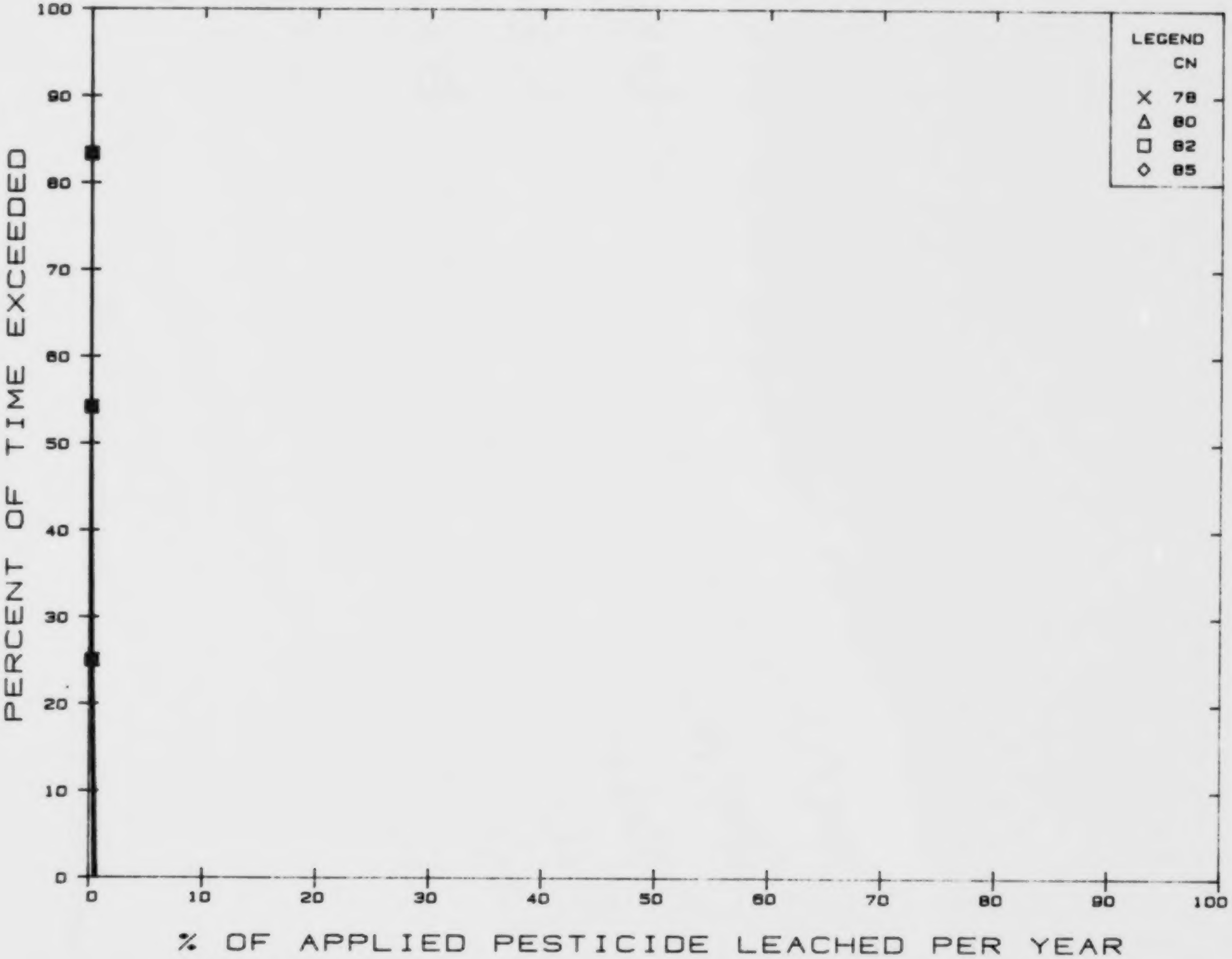


FIGURE A9-8 R=3. KS=.010

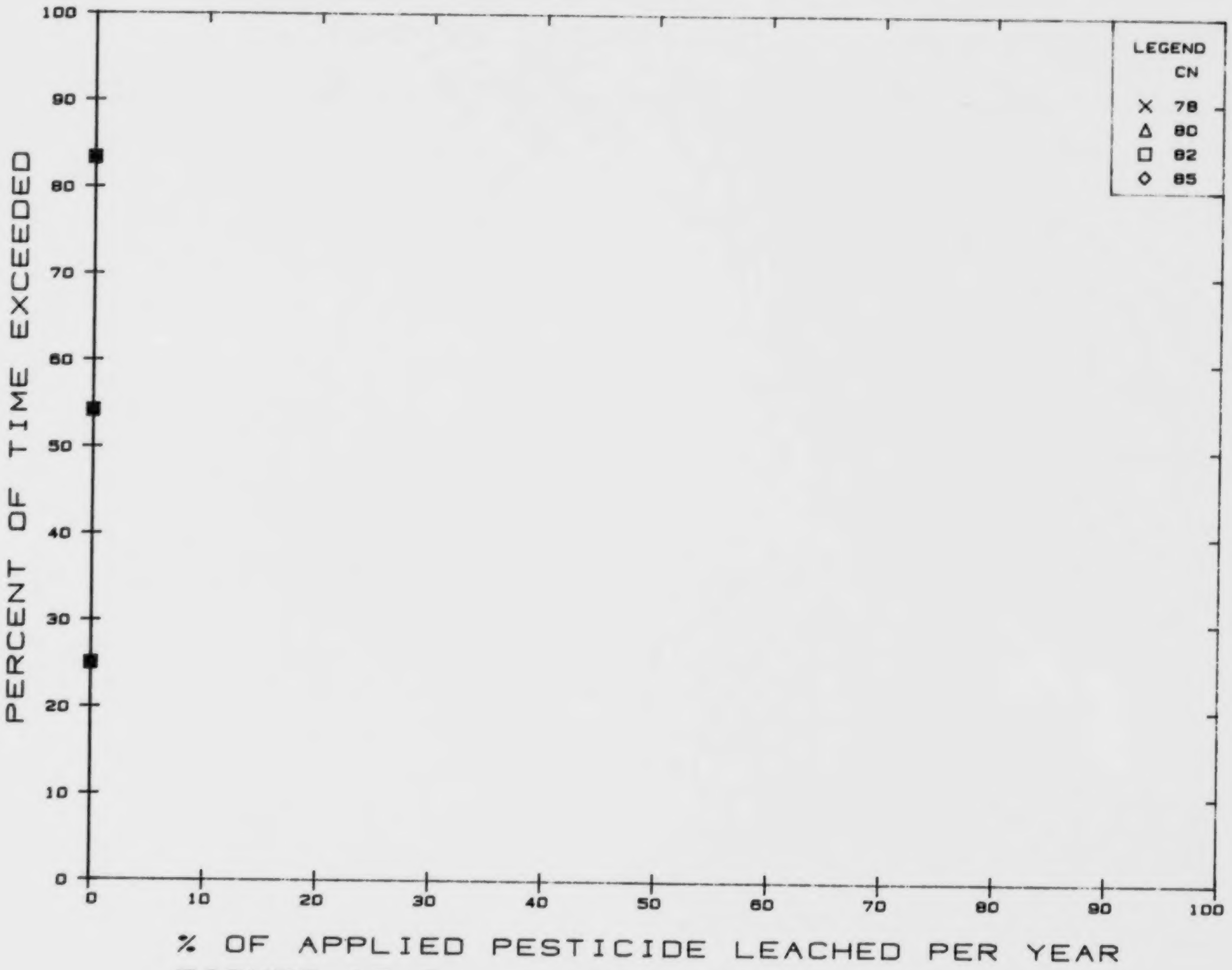


FIGURE A9-9 R=3. KS=.050

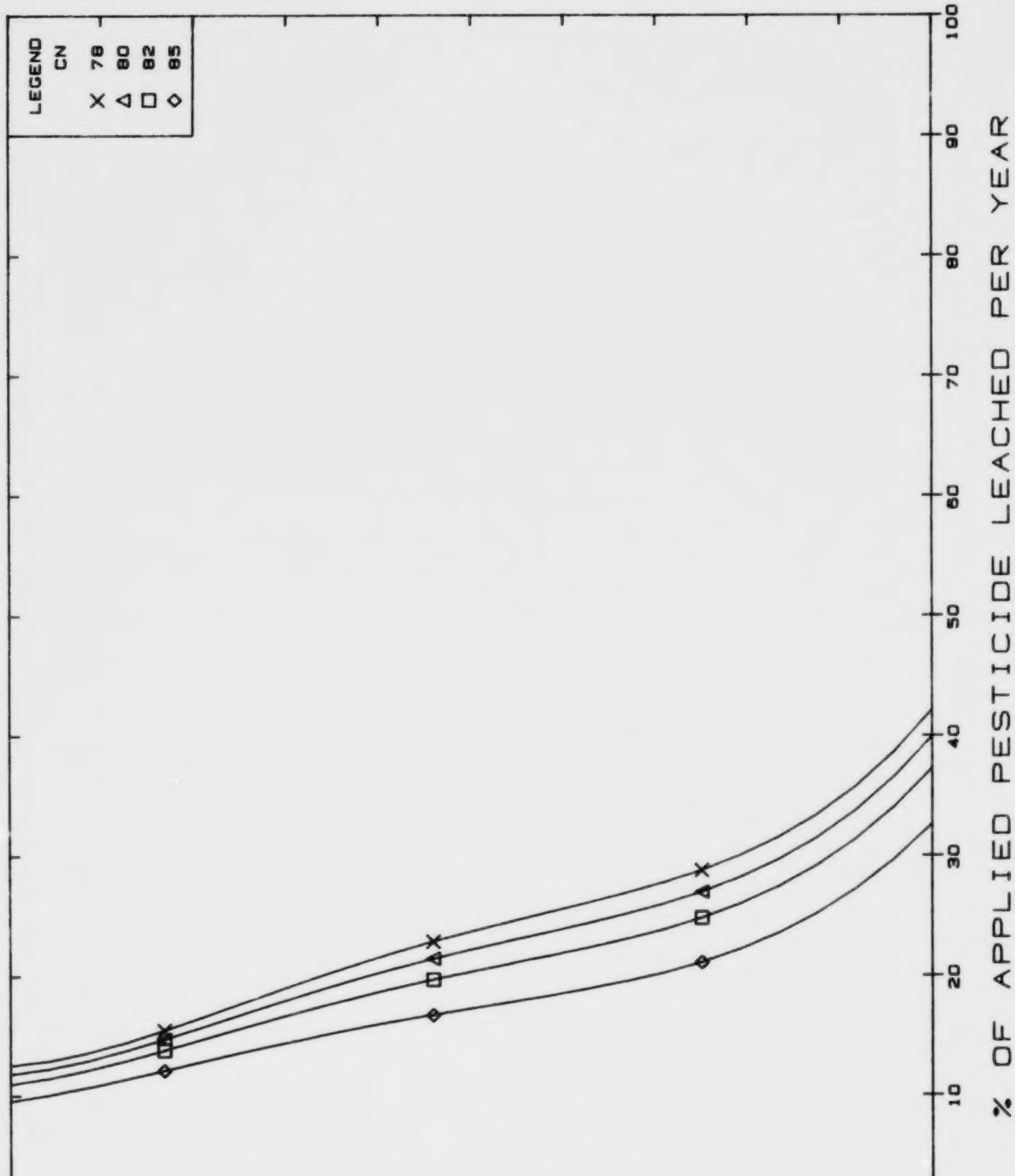


FIGURE A9-10 R=5. KS=.001

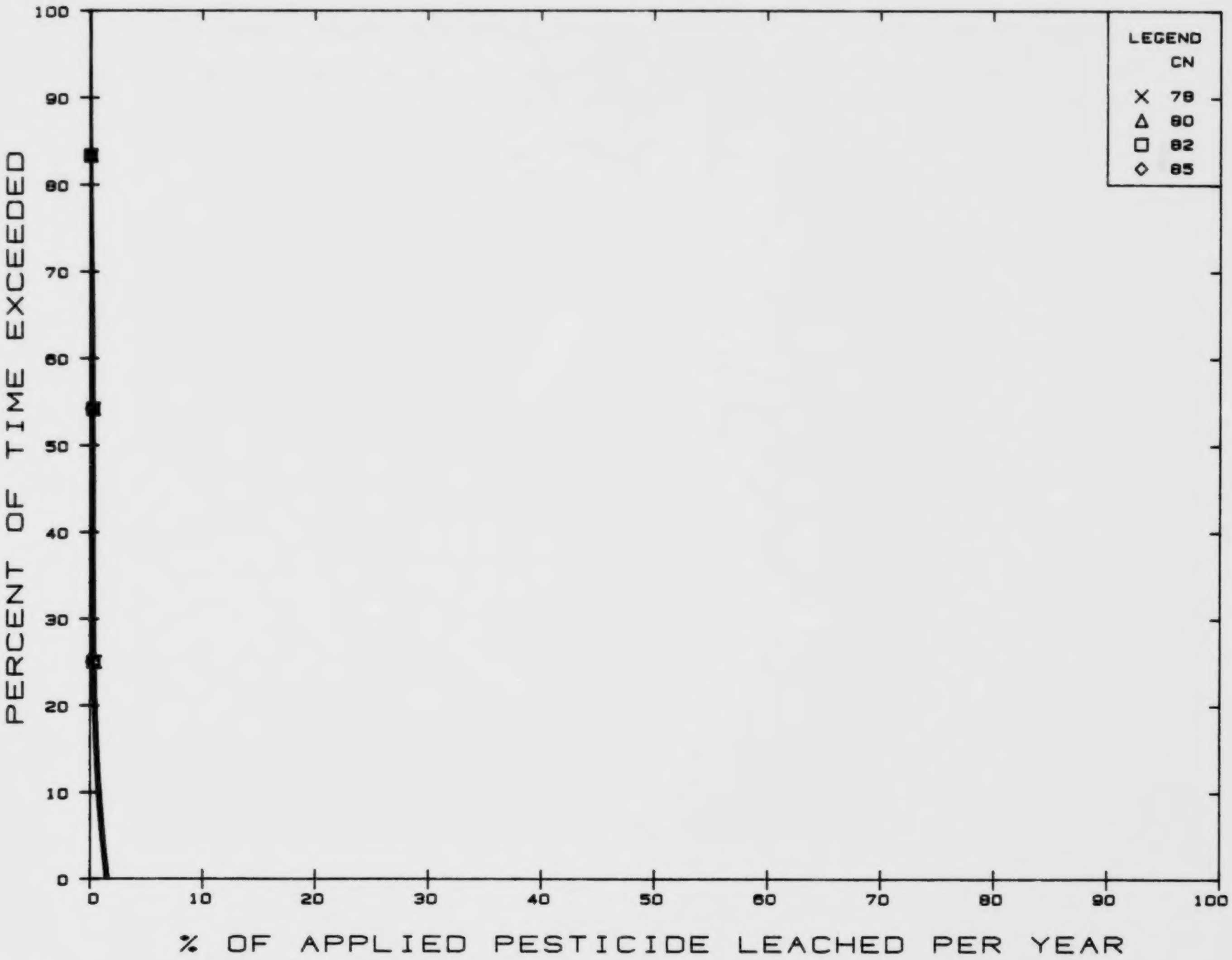


FIGURE A9-11   R=5.   KS=.005

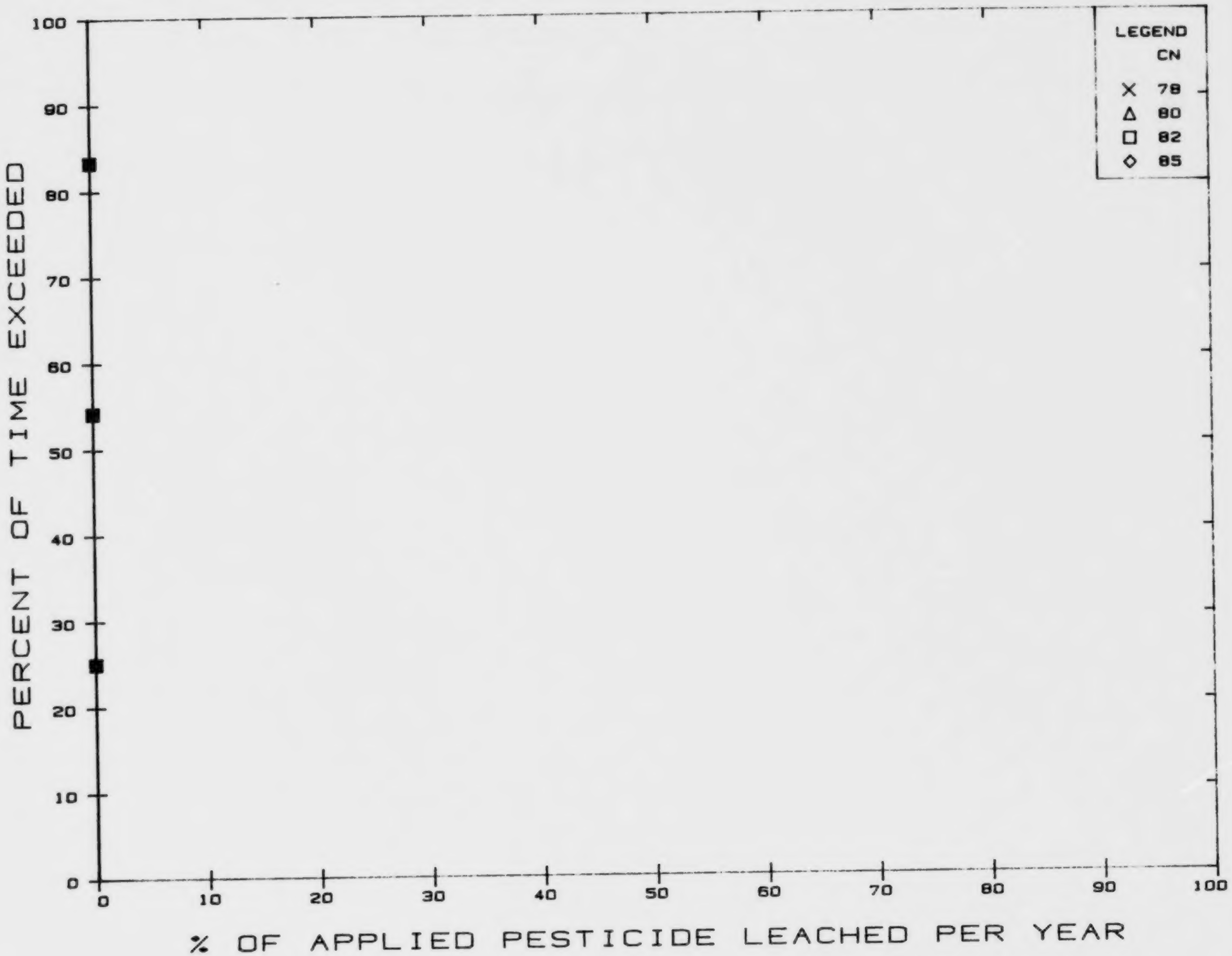


FIGURE A9-12 R=5. KS=.010

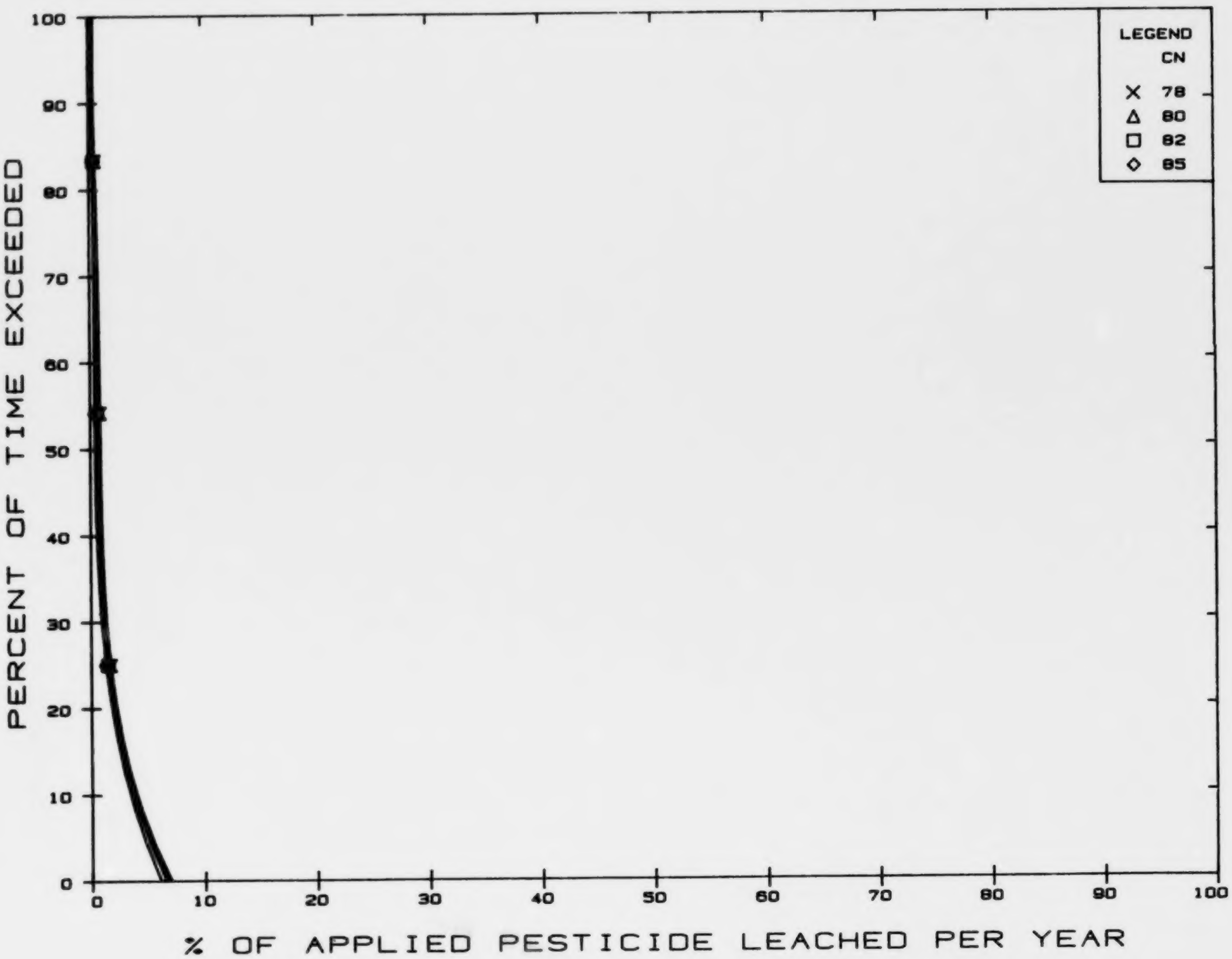


FIGURE A9-13 R=20. KS=.001

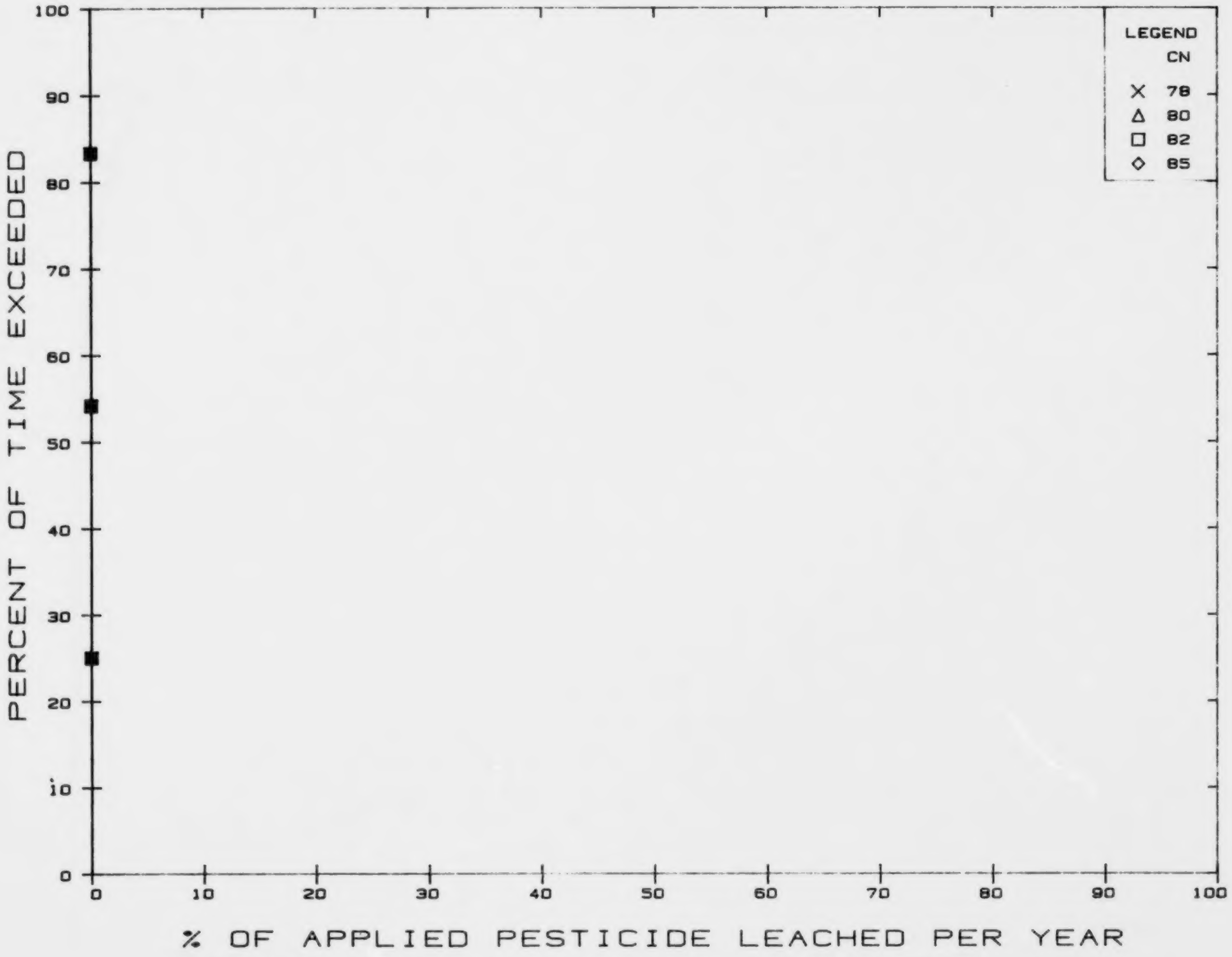


FIGURE A9-14 R=20. KS=.005

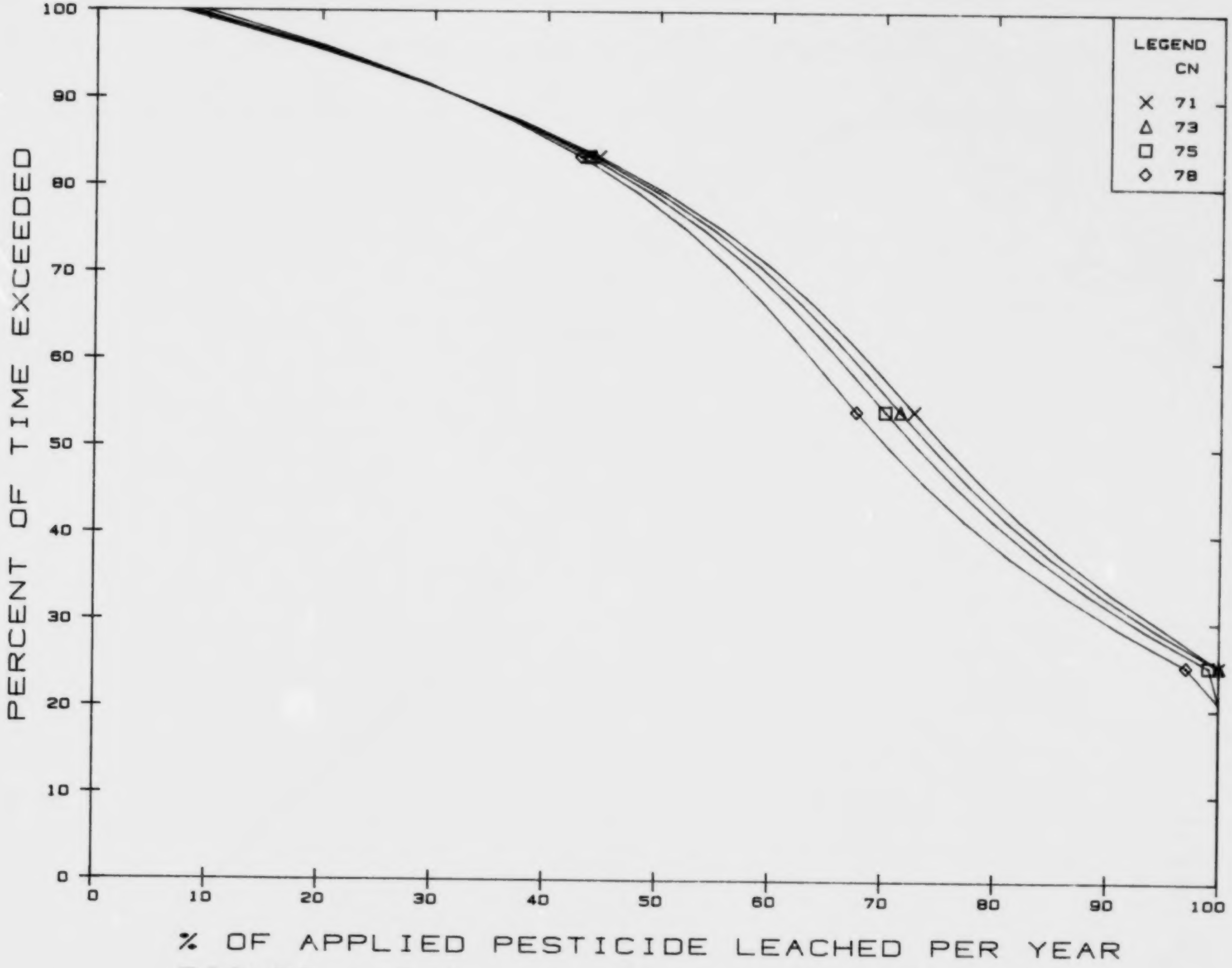


FIGURE A10-1 R=1. KS=.001

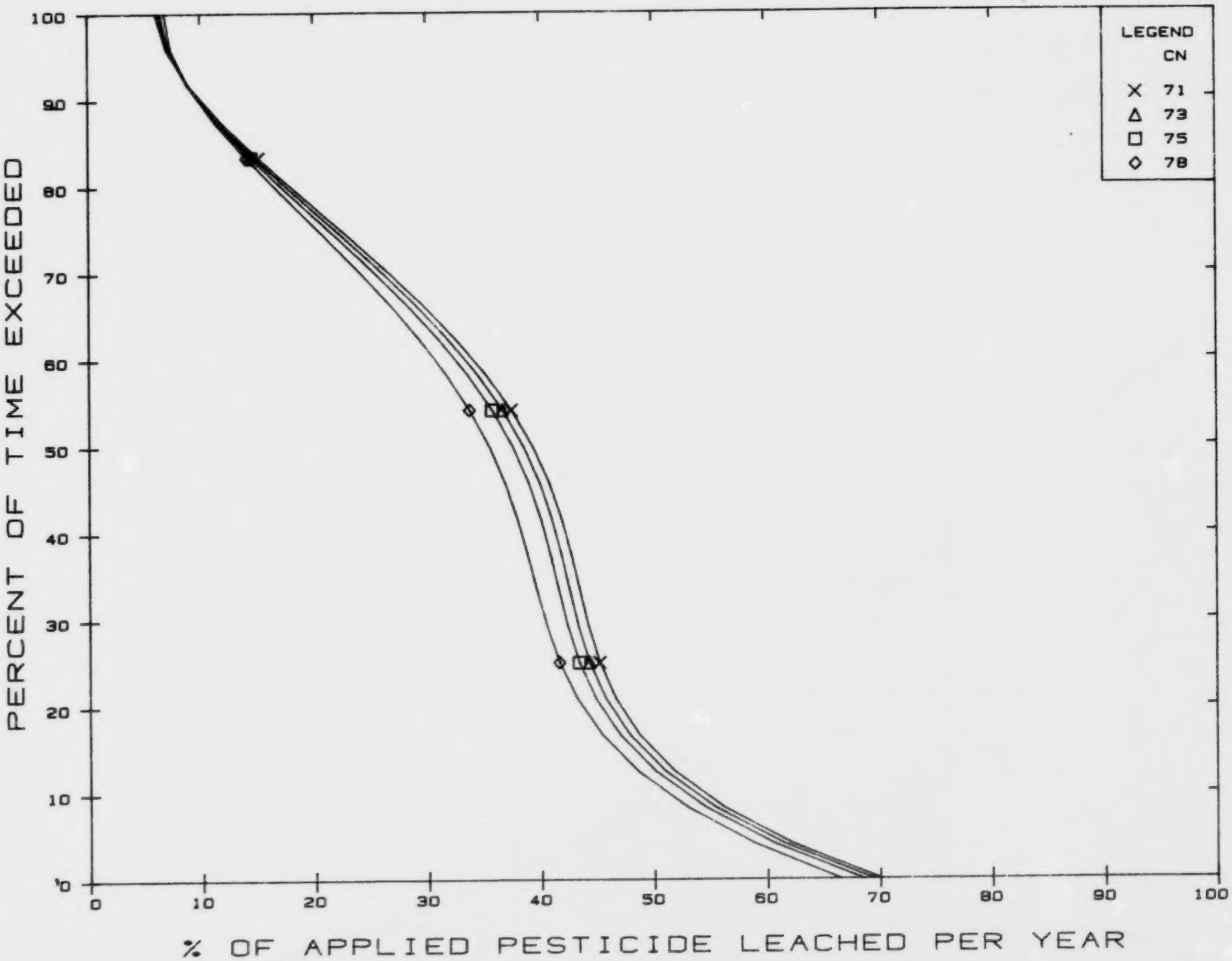


FIGURE A10-2 R=1. KS=.005

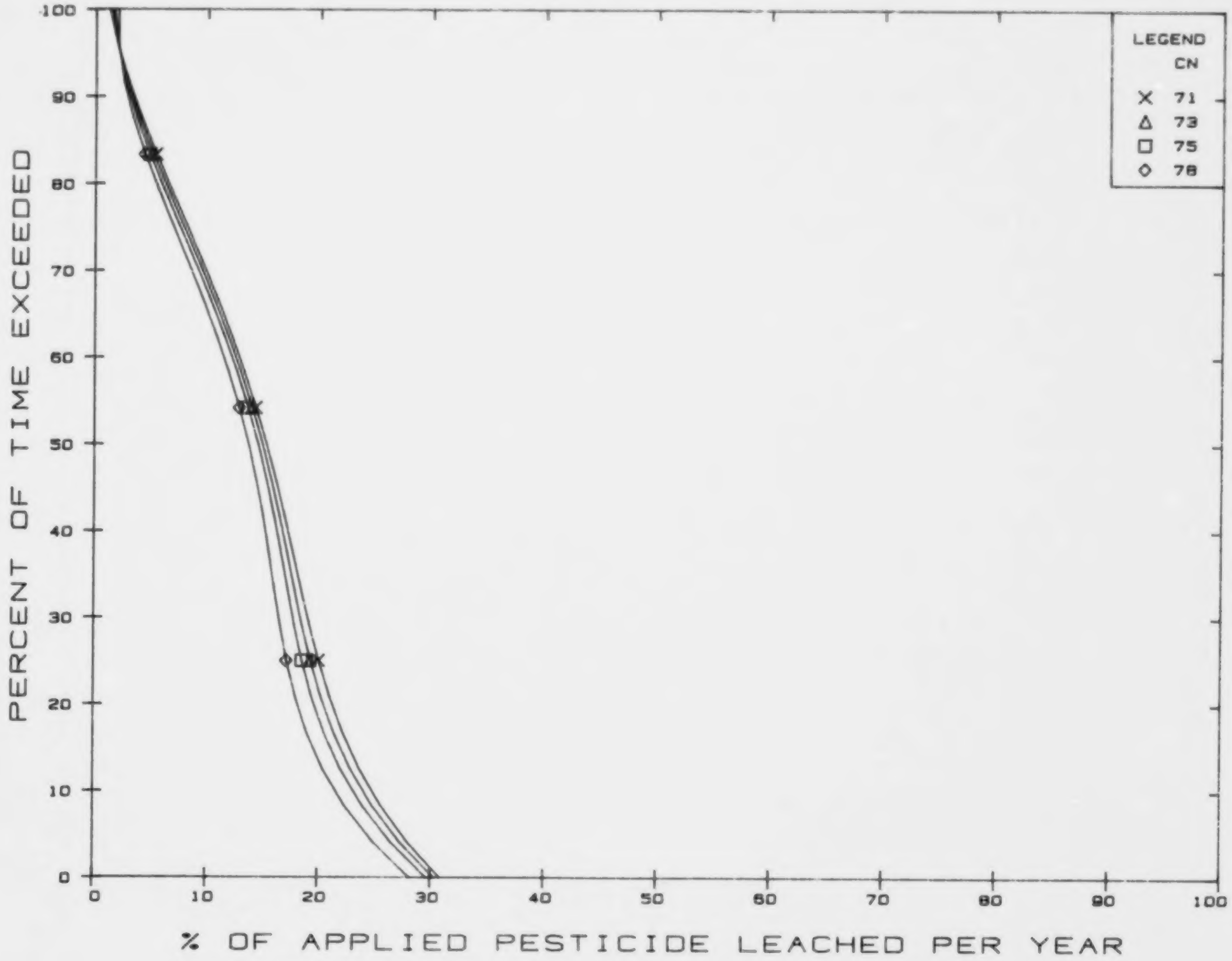


FIGURE A10-3 R=1. KS=.010

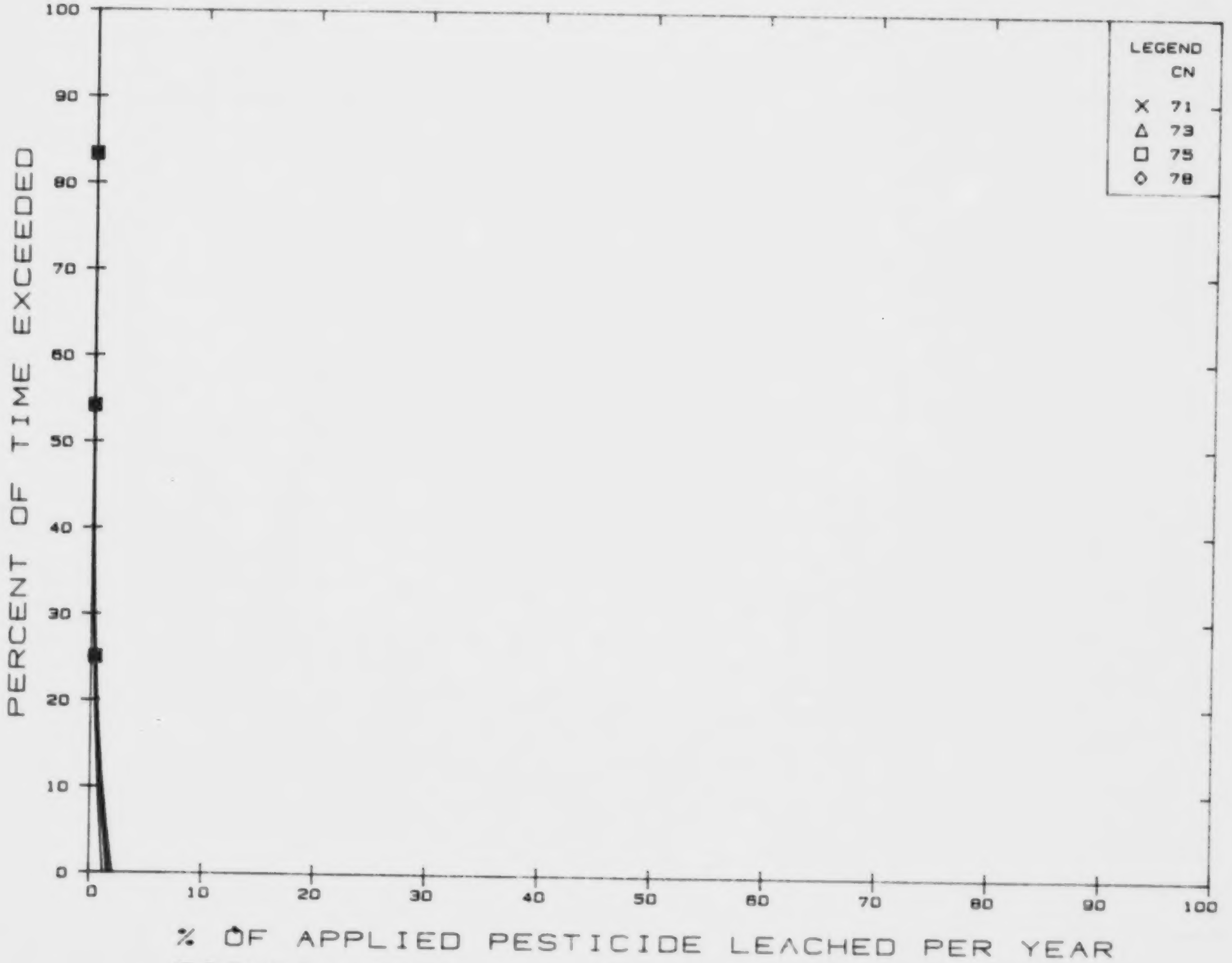


FIGURE A10-4 R=1. KS=.050

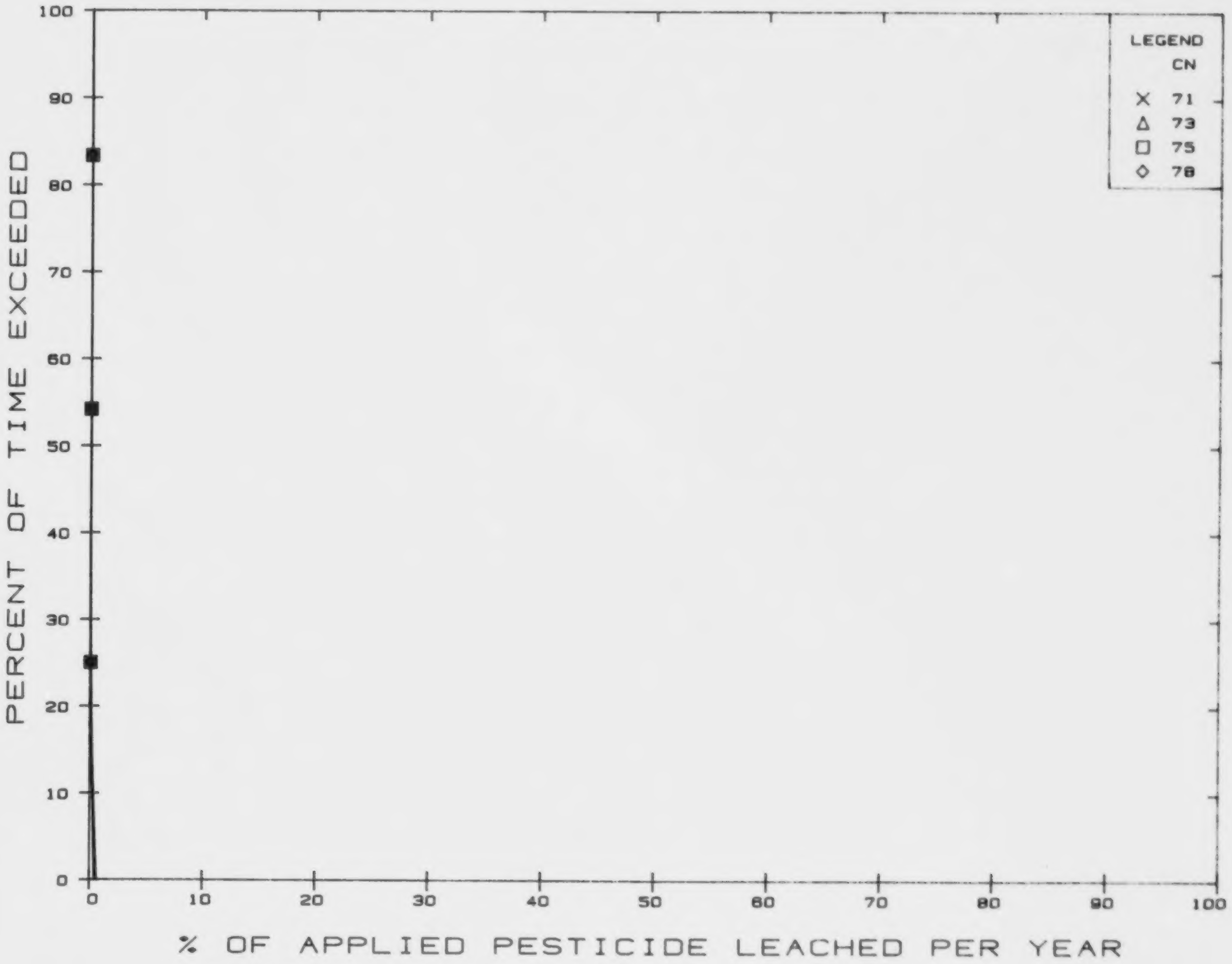


FIGURE A10-5 R=1. KS=.100

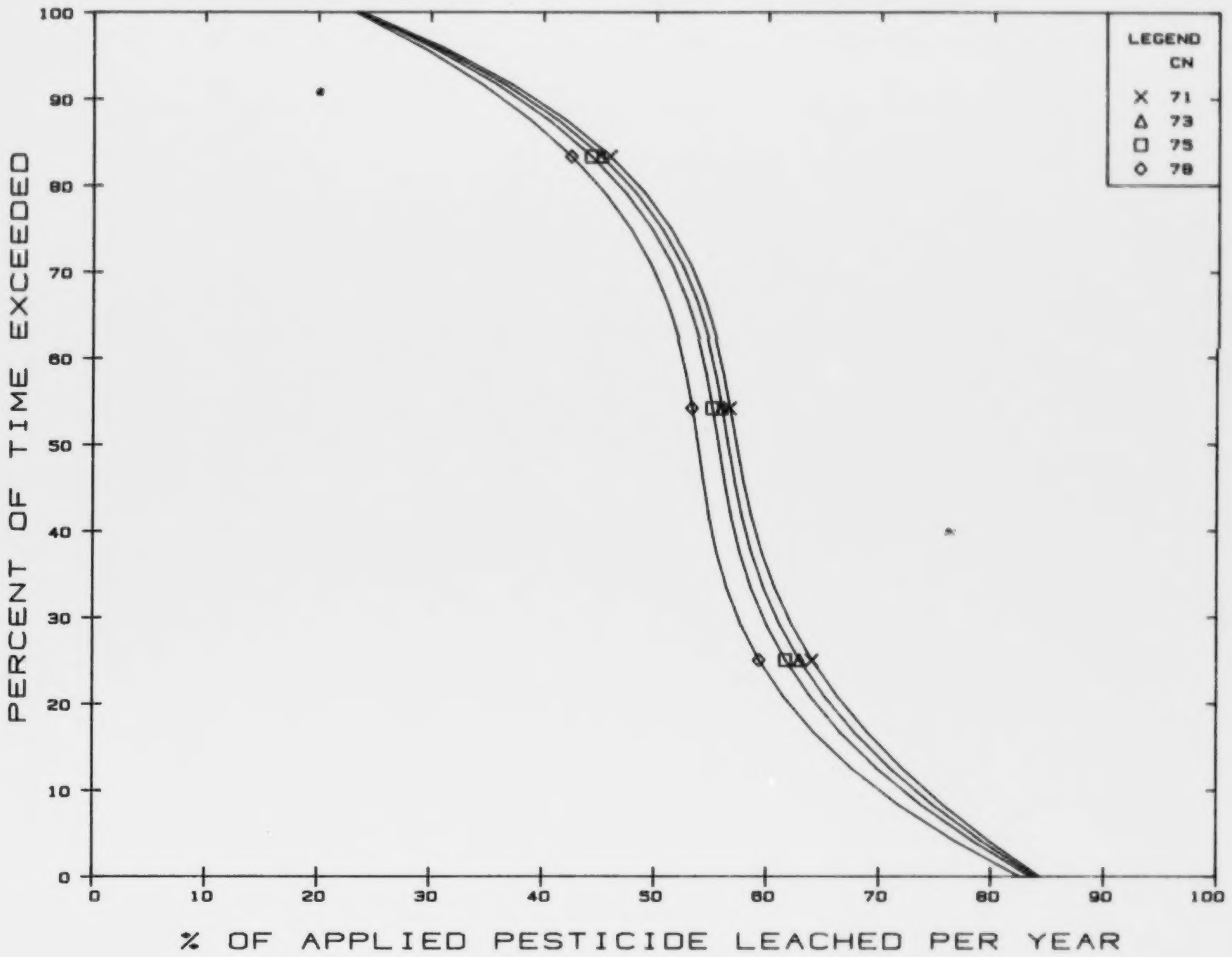


FIGURE A10-6 R=3. KS=.001

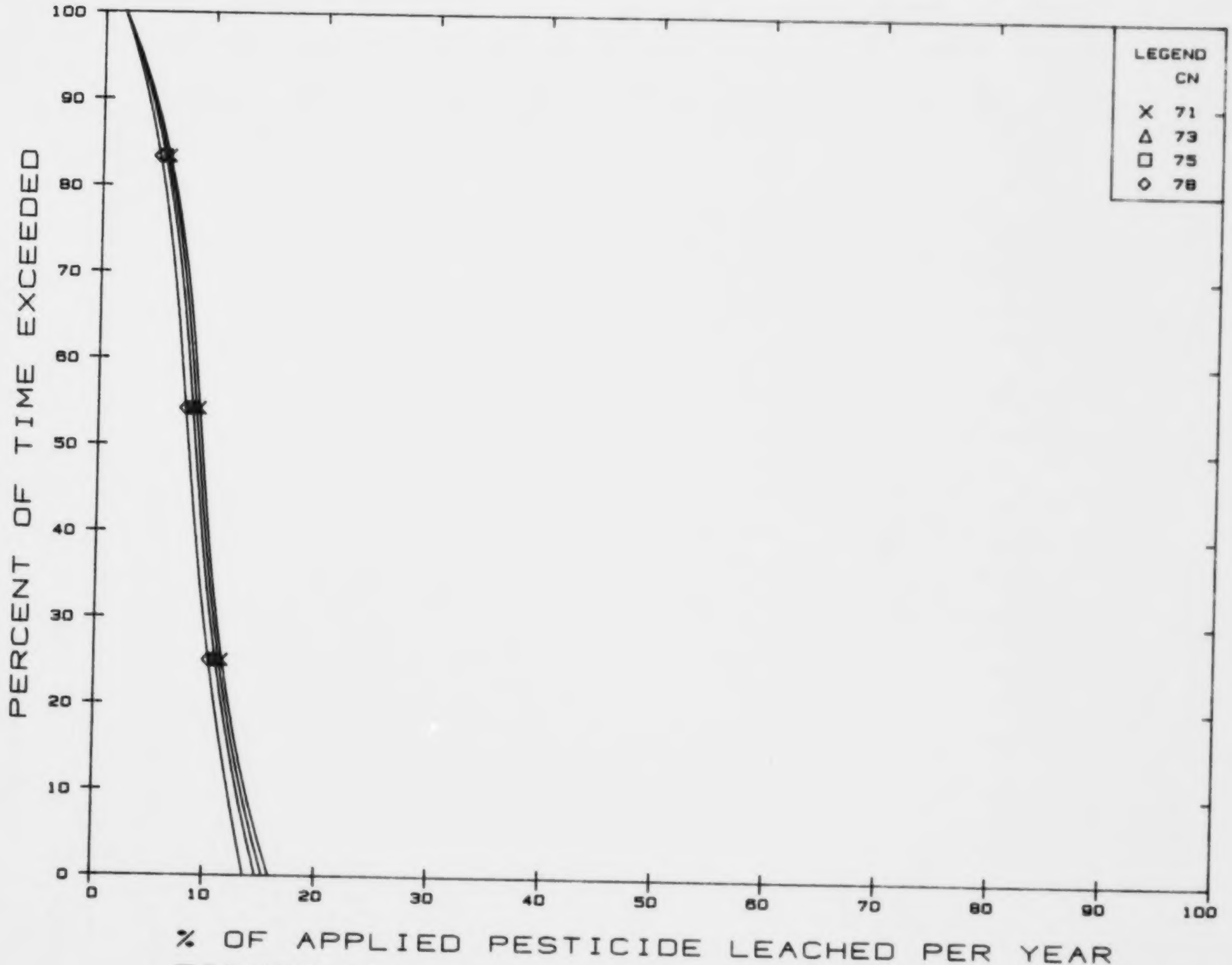


FIGURE A10-7 R=3. KS=.005

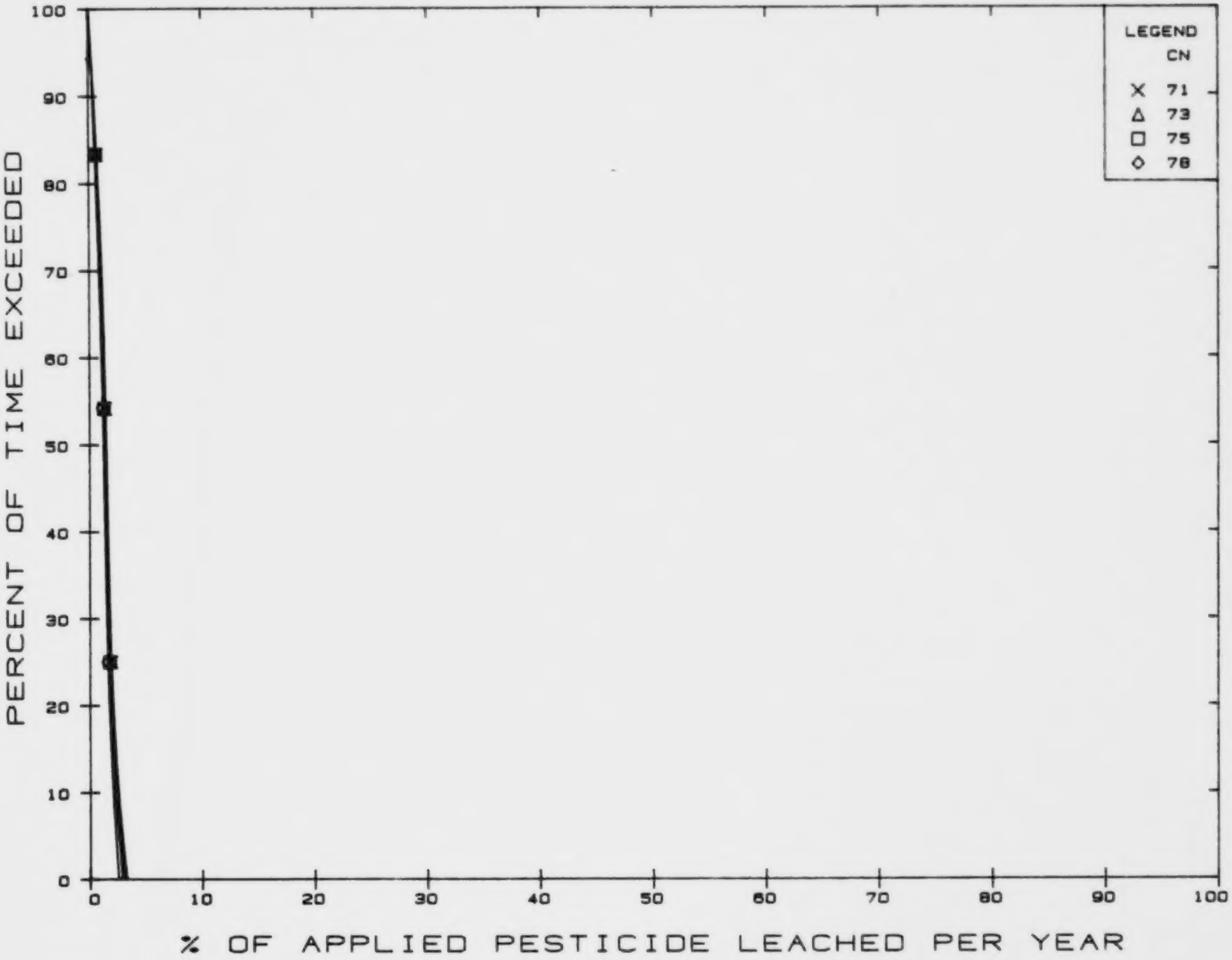


FIGURE A10-8 R=3. KS=.010

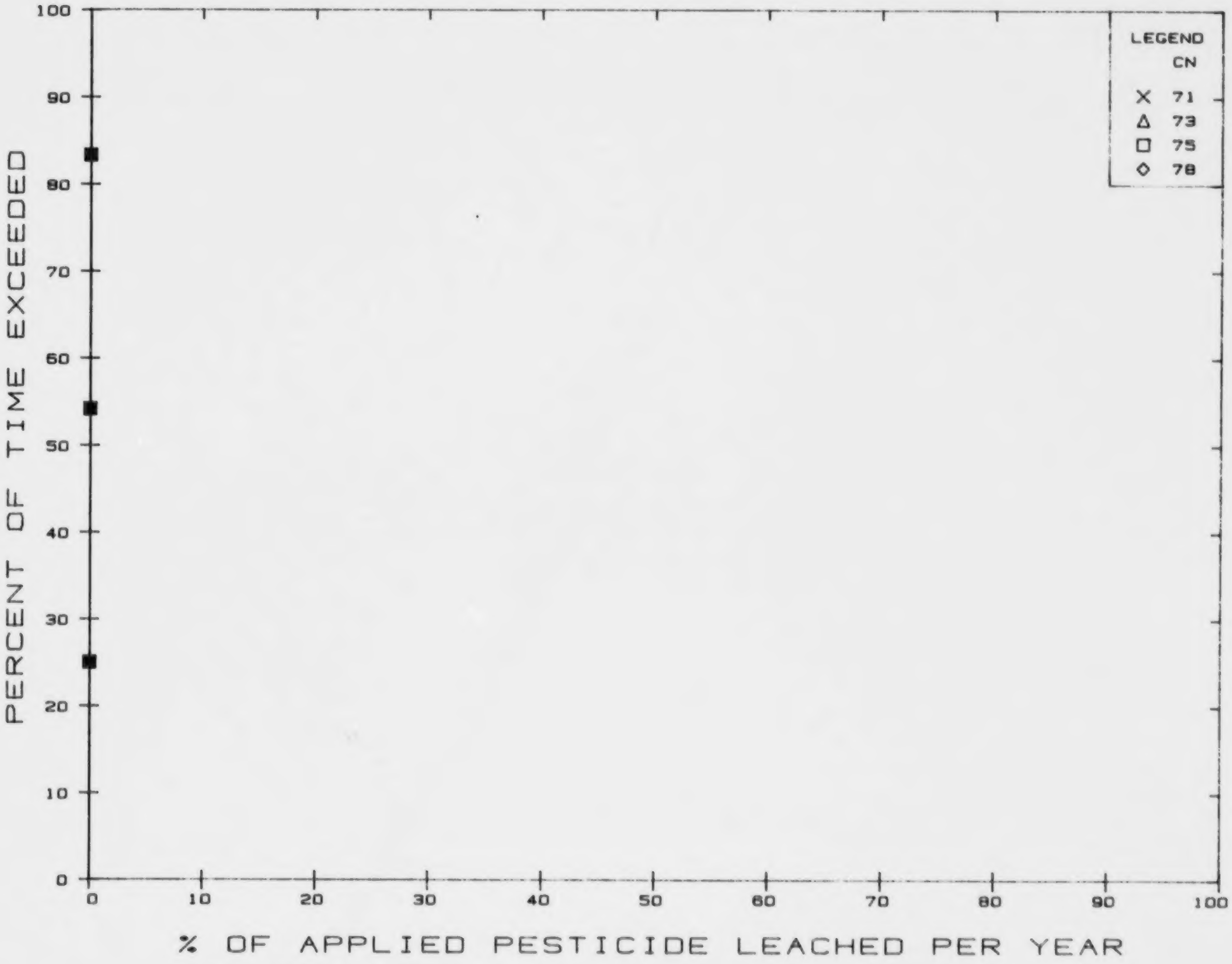


FIGURE A10-9 R=3. KS=.050

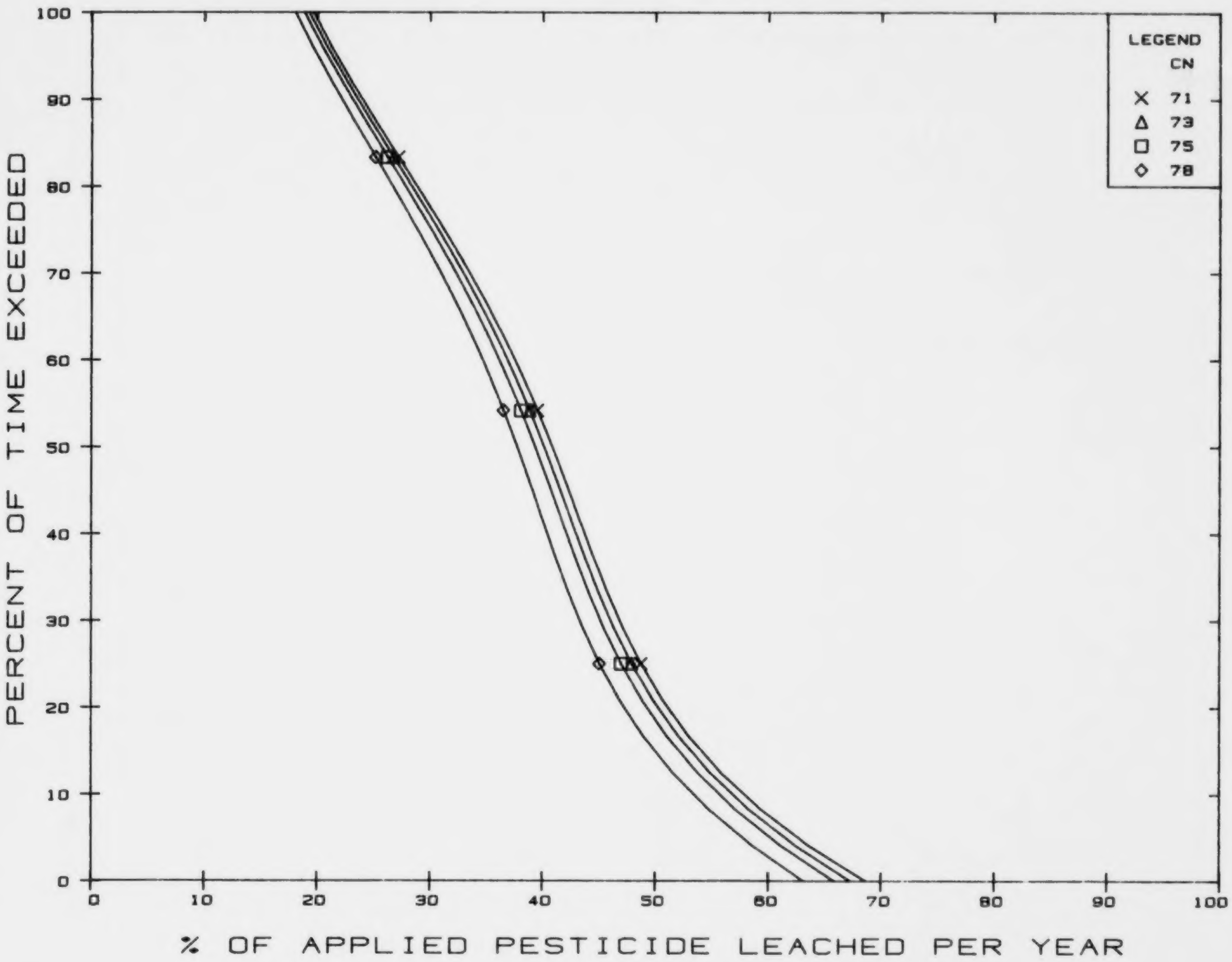


FIGURE A10-10 R=5. KS=.001

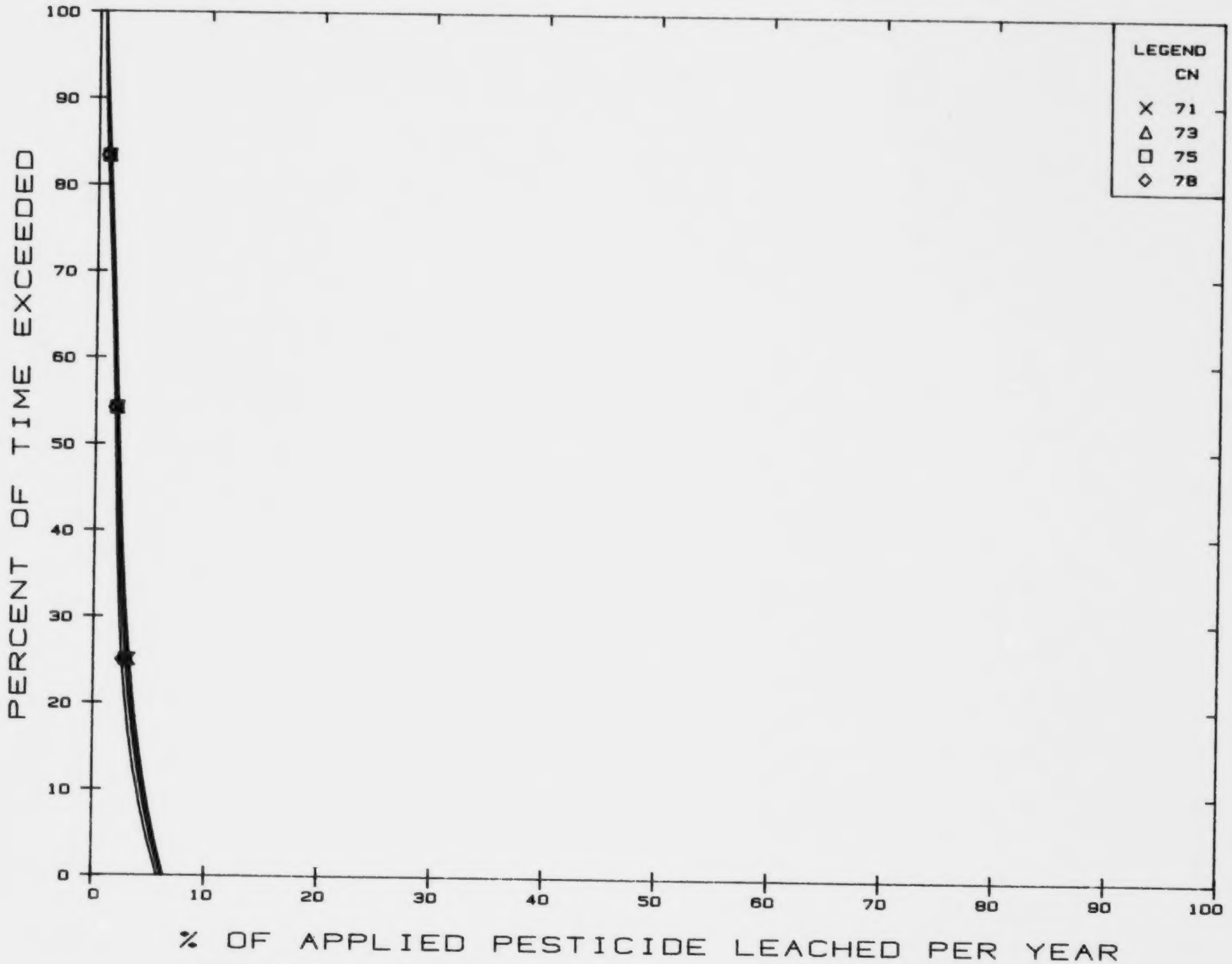


FIGURE A10-11 R=5. KS=.005

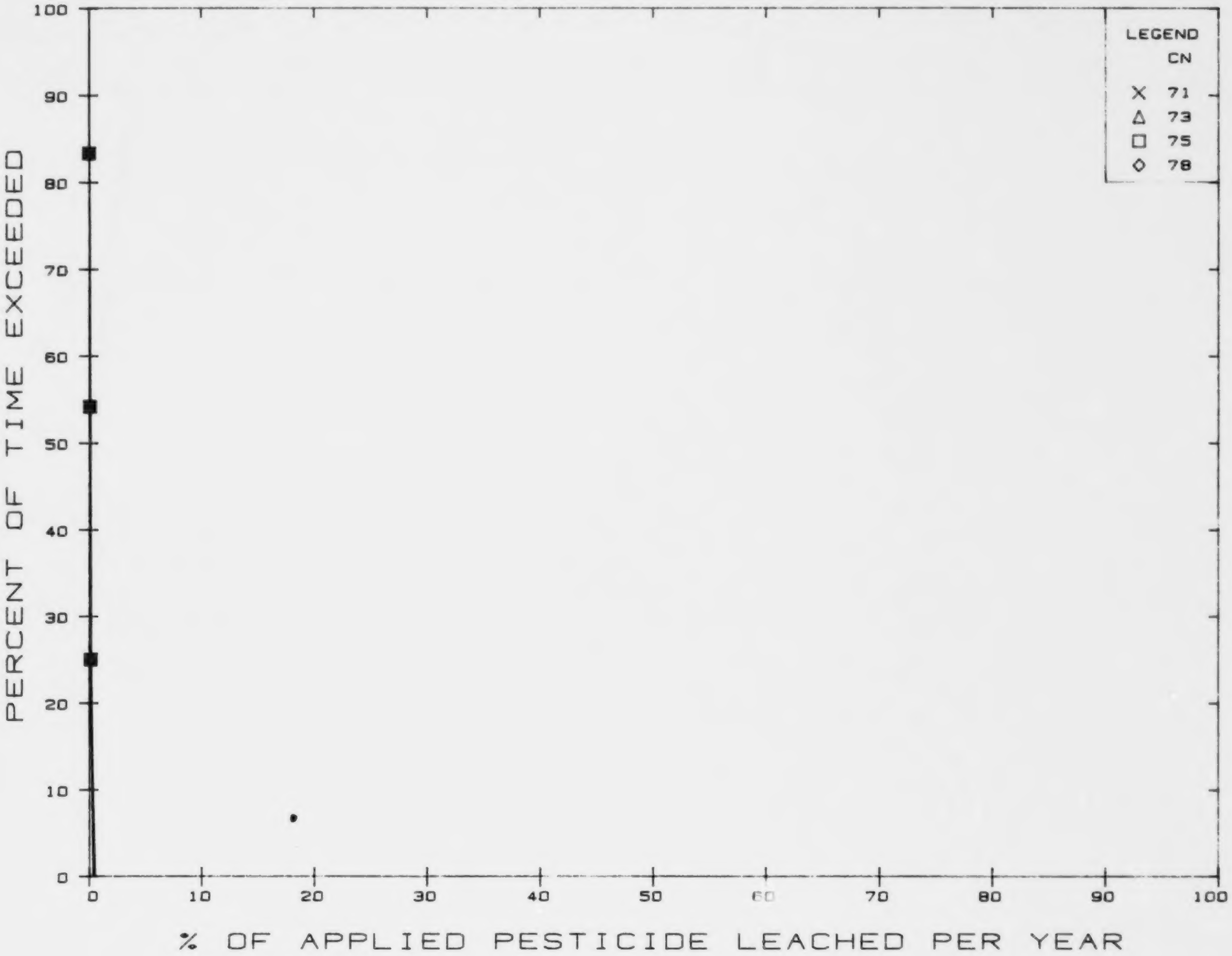


FIGURE A10-12 R=5. KS=.010

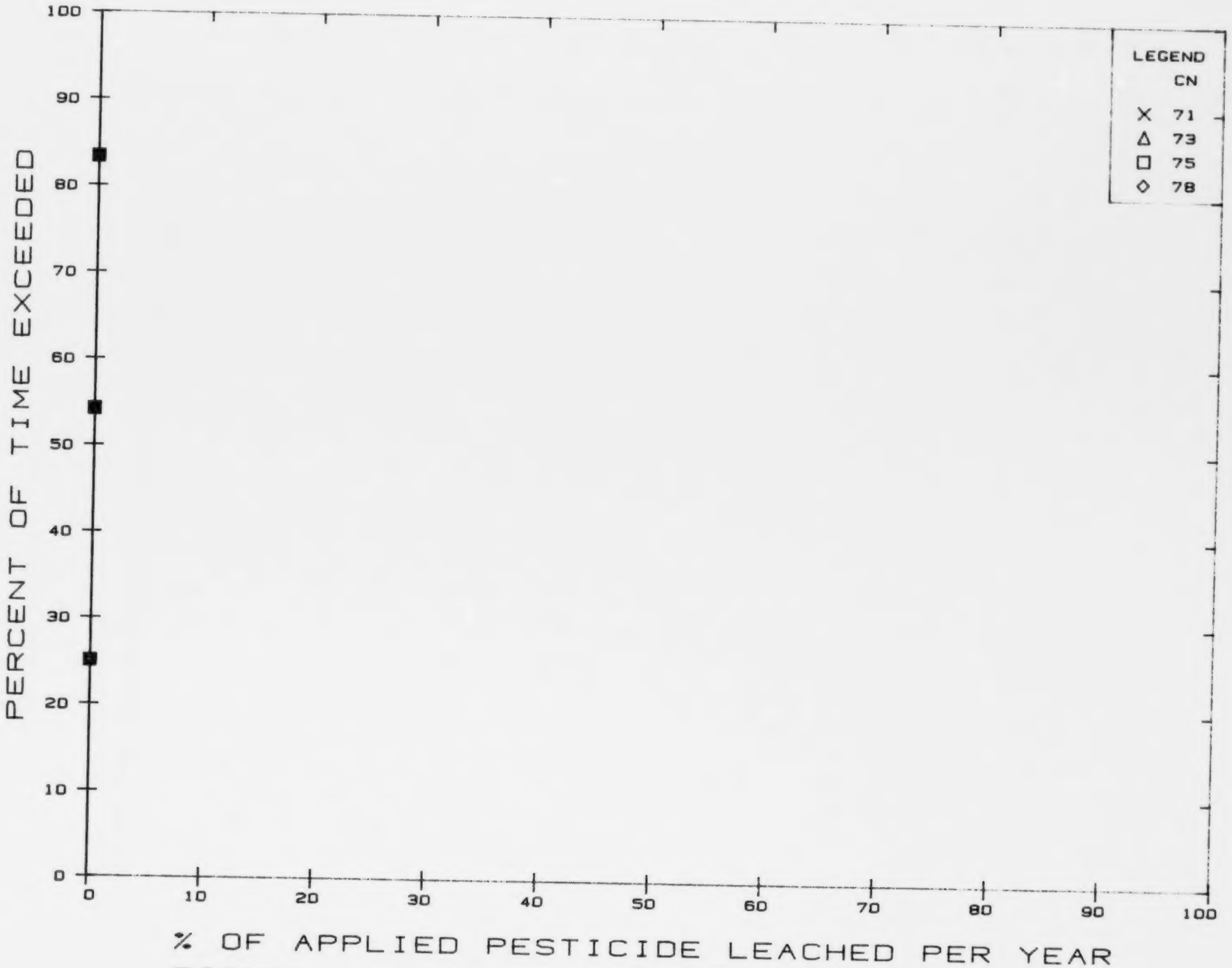


FIGURE A10-13 R=5. KS=.050

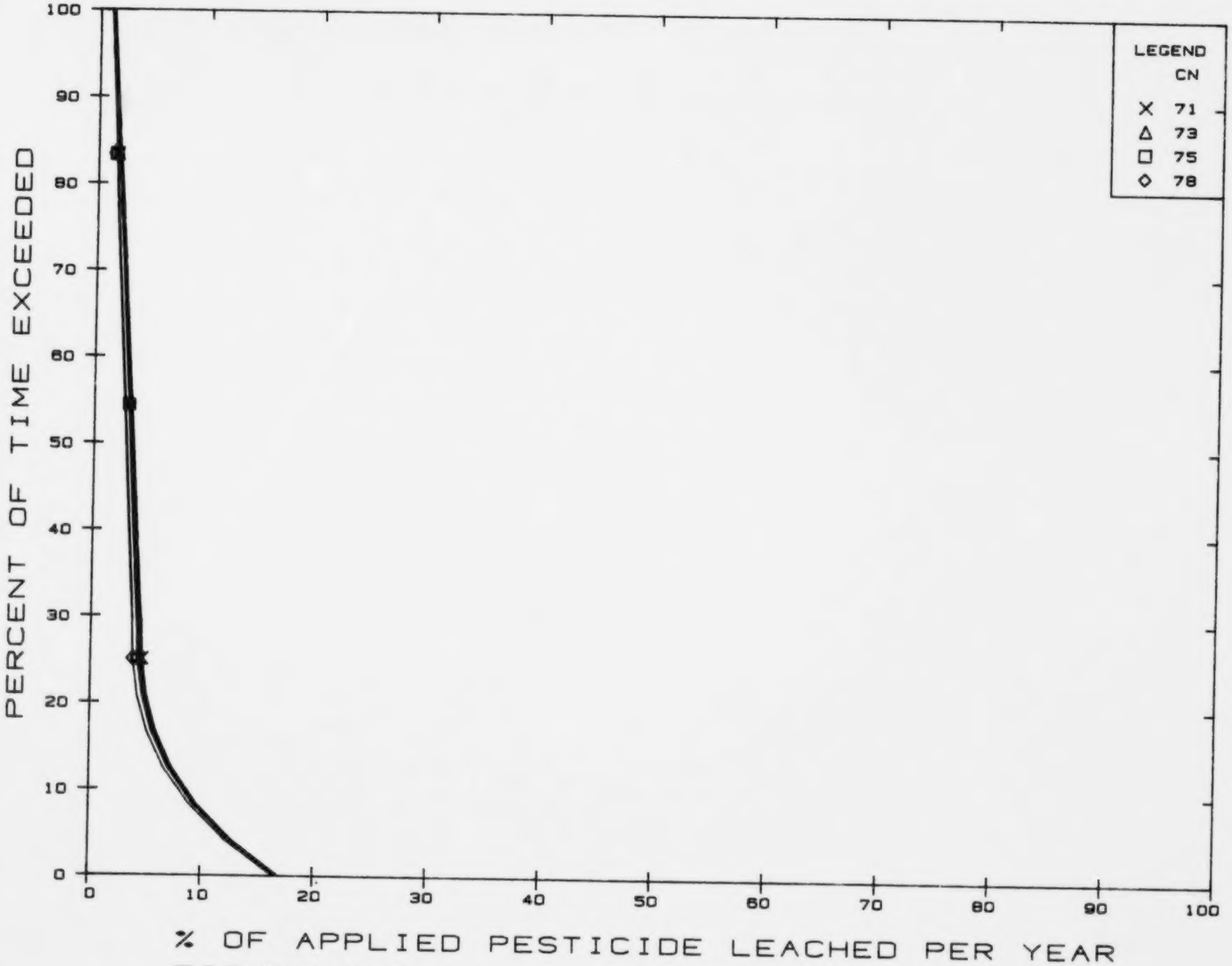


FIGURE A10-14 R=20. KS=.001

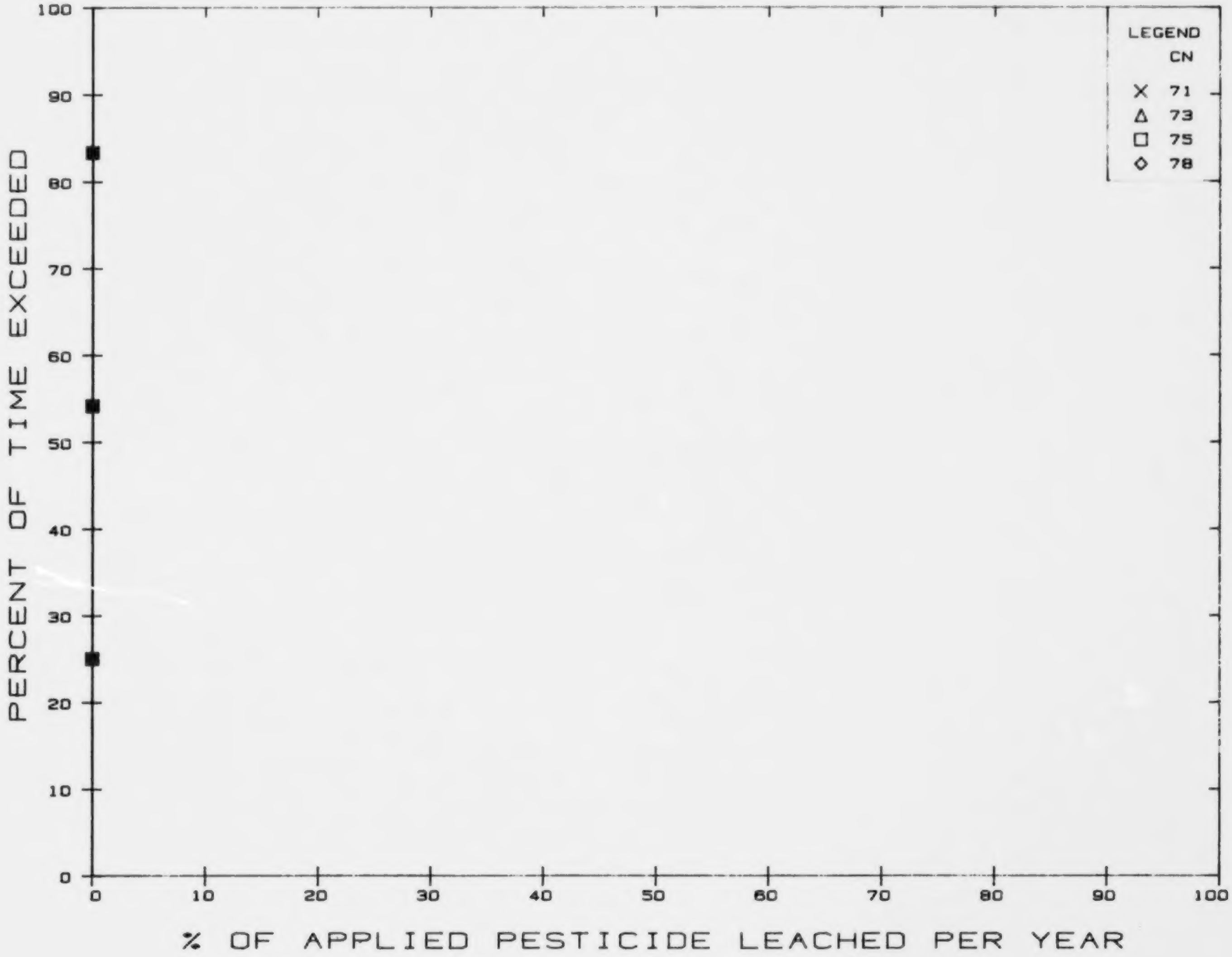


FIGURE A10-15 R=20. KS=.005

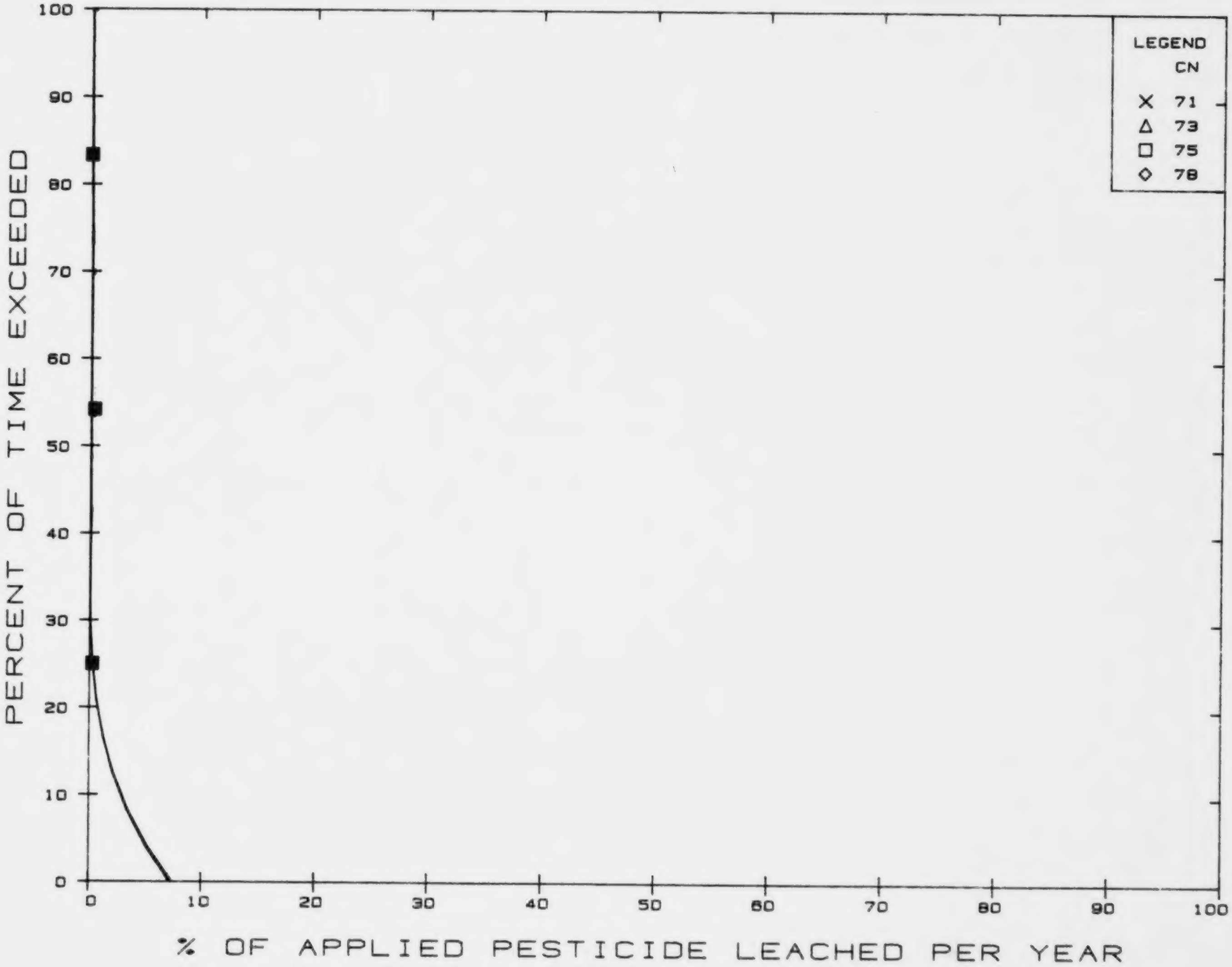


FIGURE A10-16 R=50. KS=.001

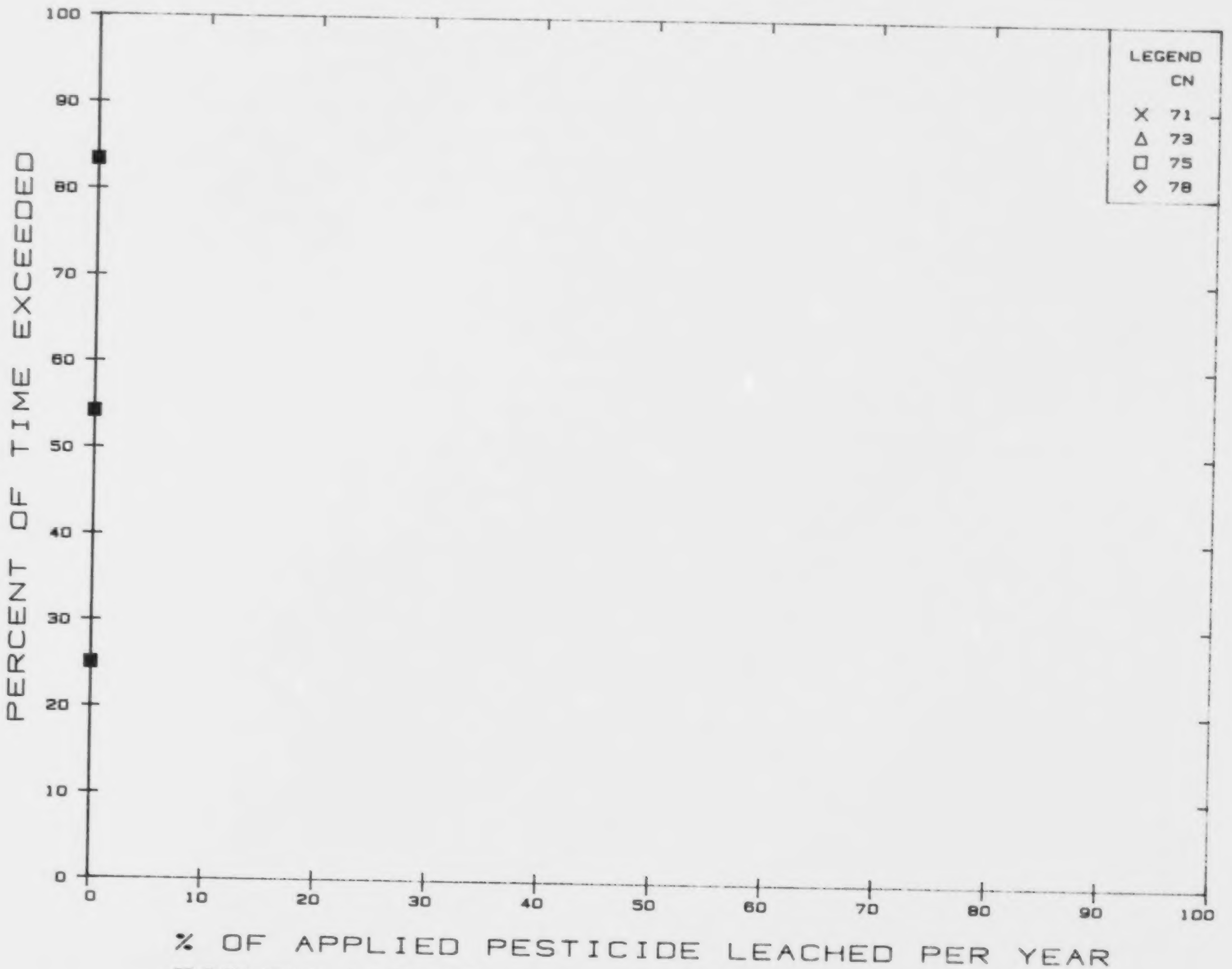


FIGURE A10-17 R=50. KS=.005

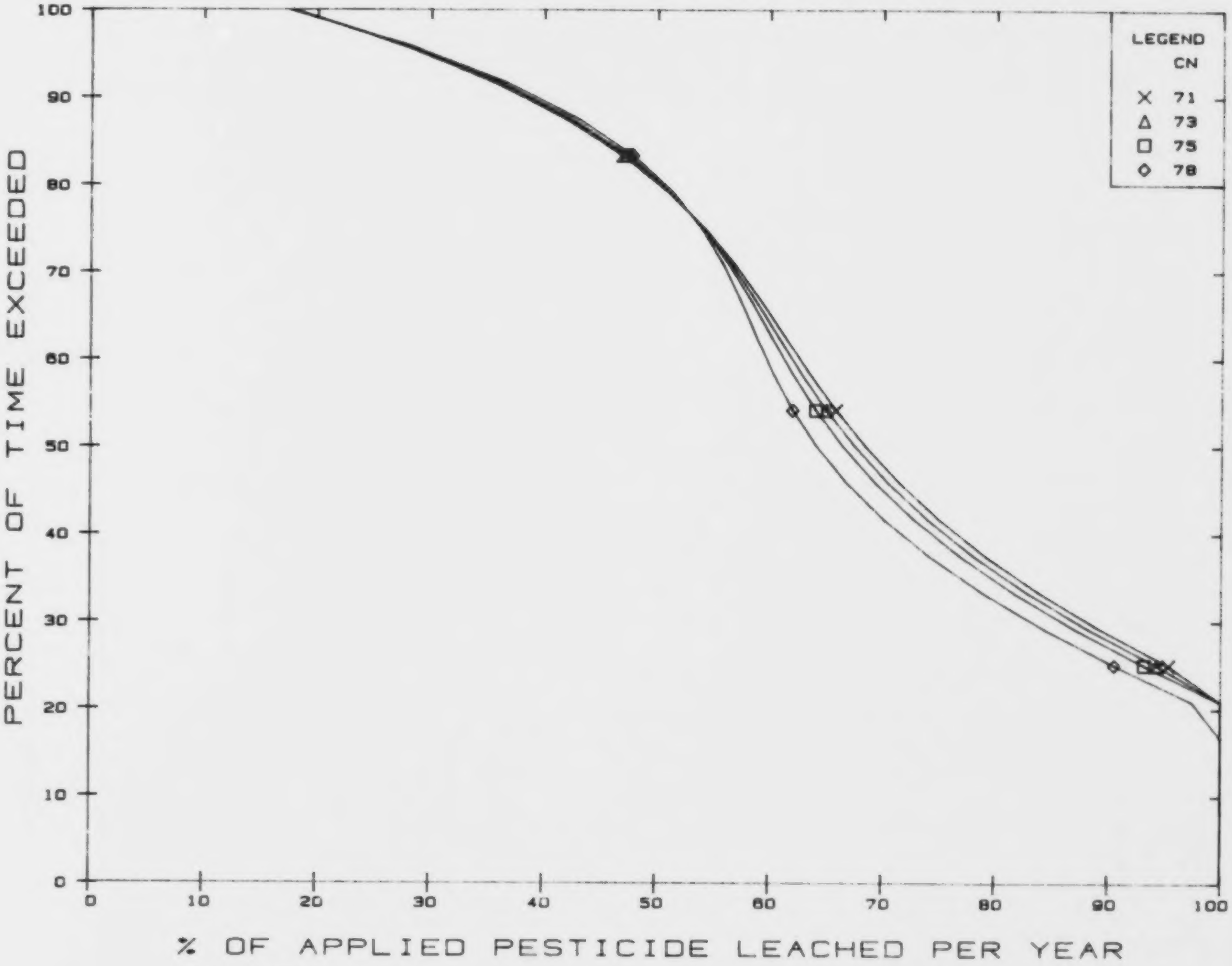


FIGURE A11-1 R=1. KS=.001

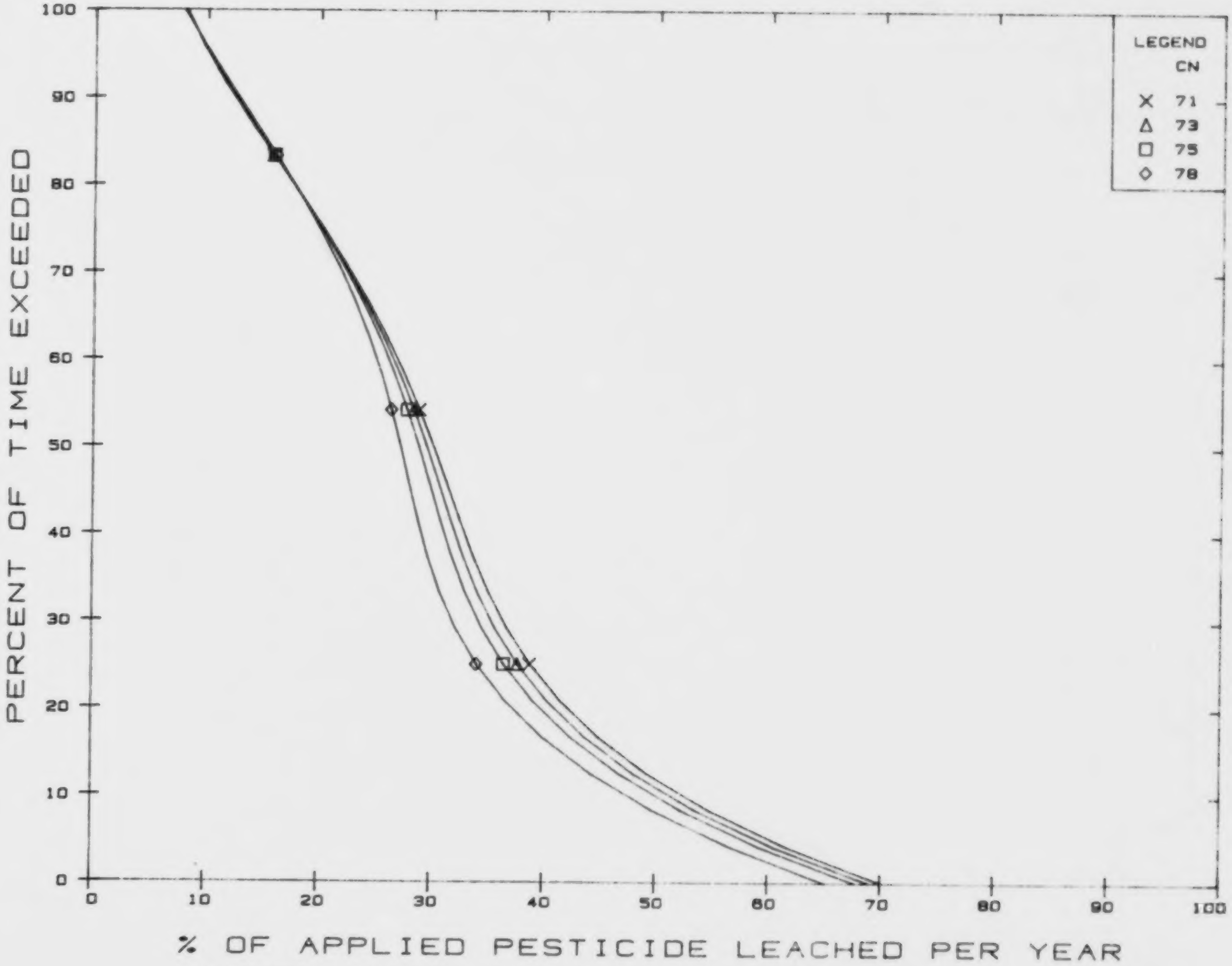


FIGURE A11-2 R=1. KS=.005

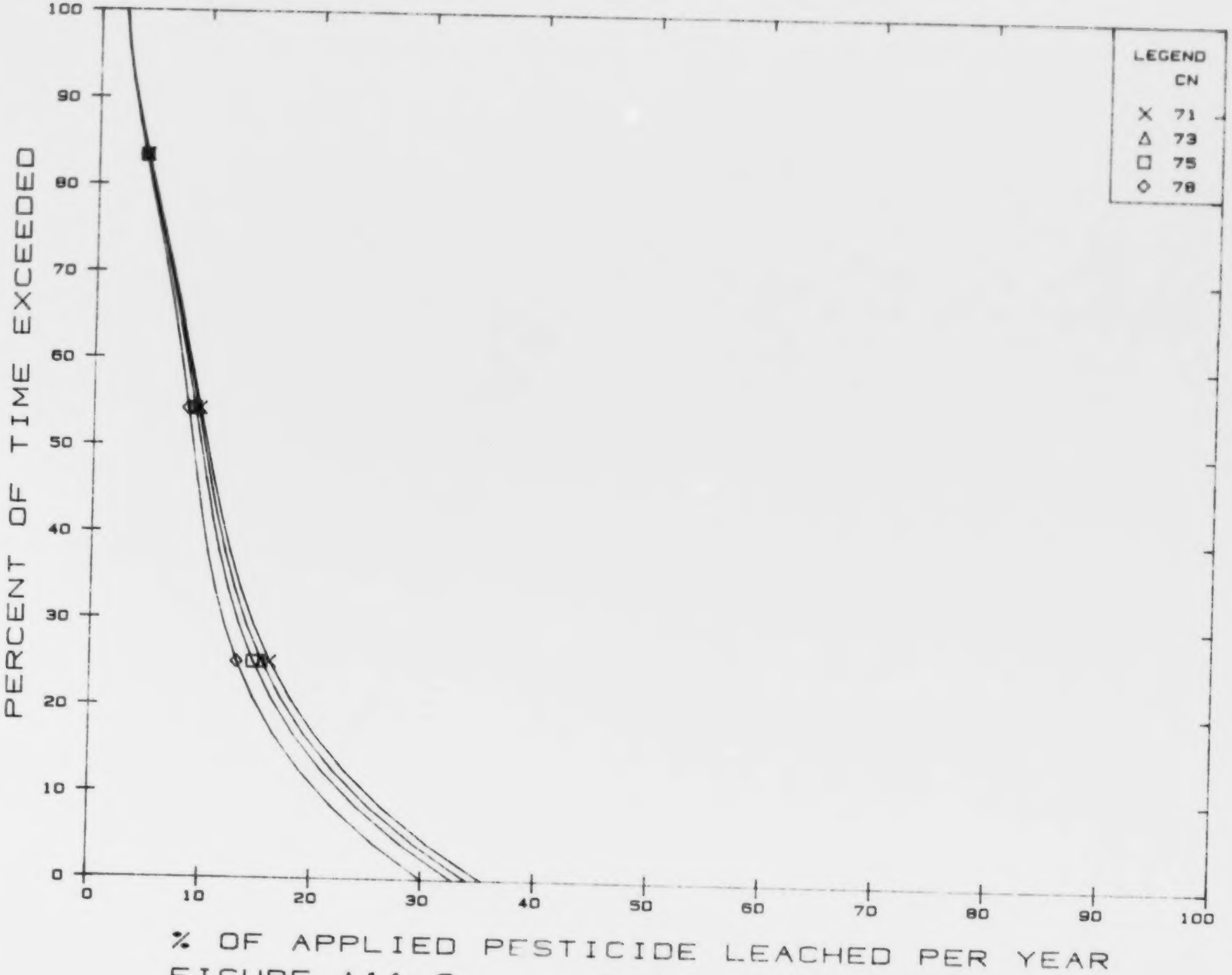


FIGURE A11-3 R=1. KS=.010

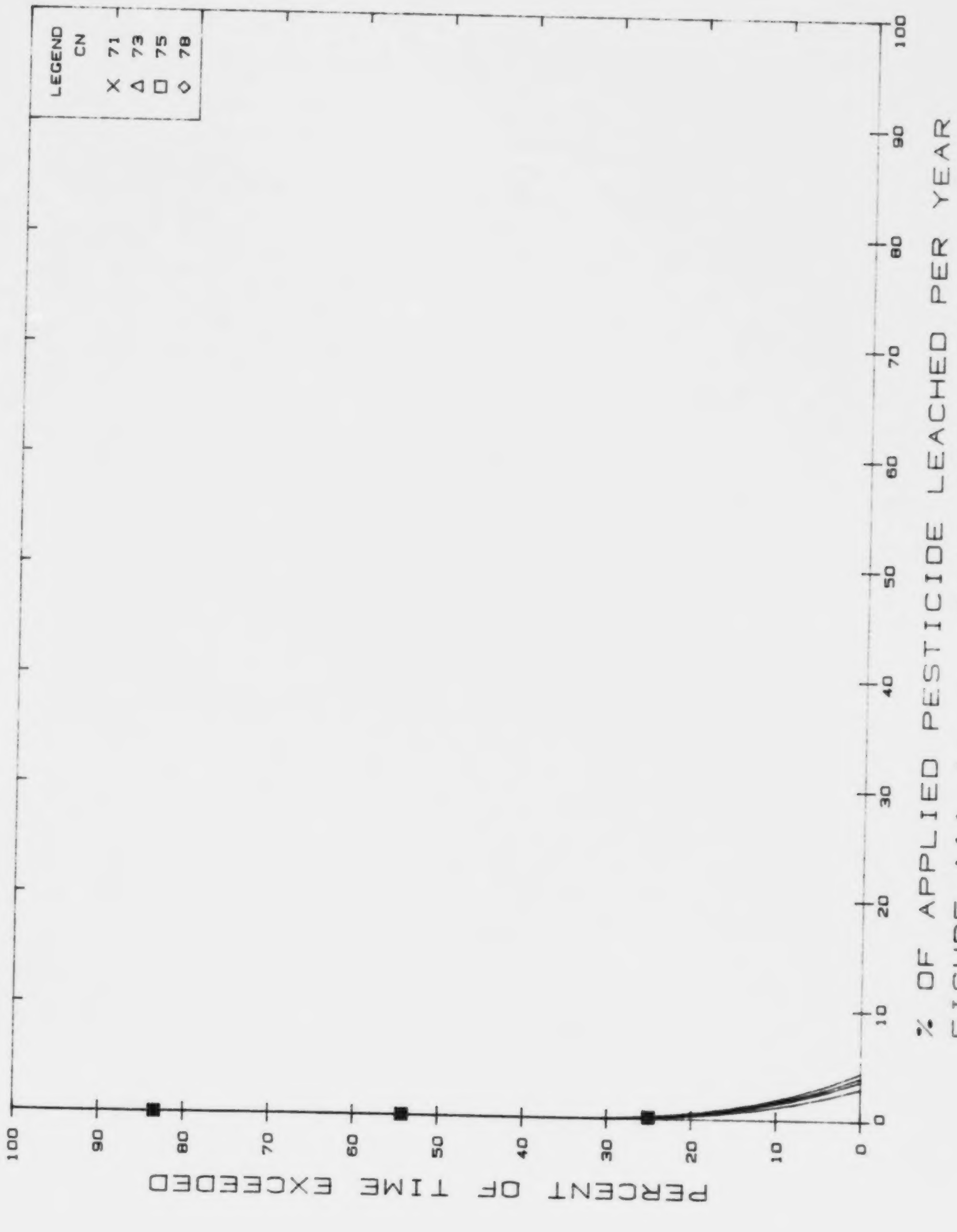


FIGURE A11-4 R=1. KS=.050

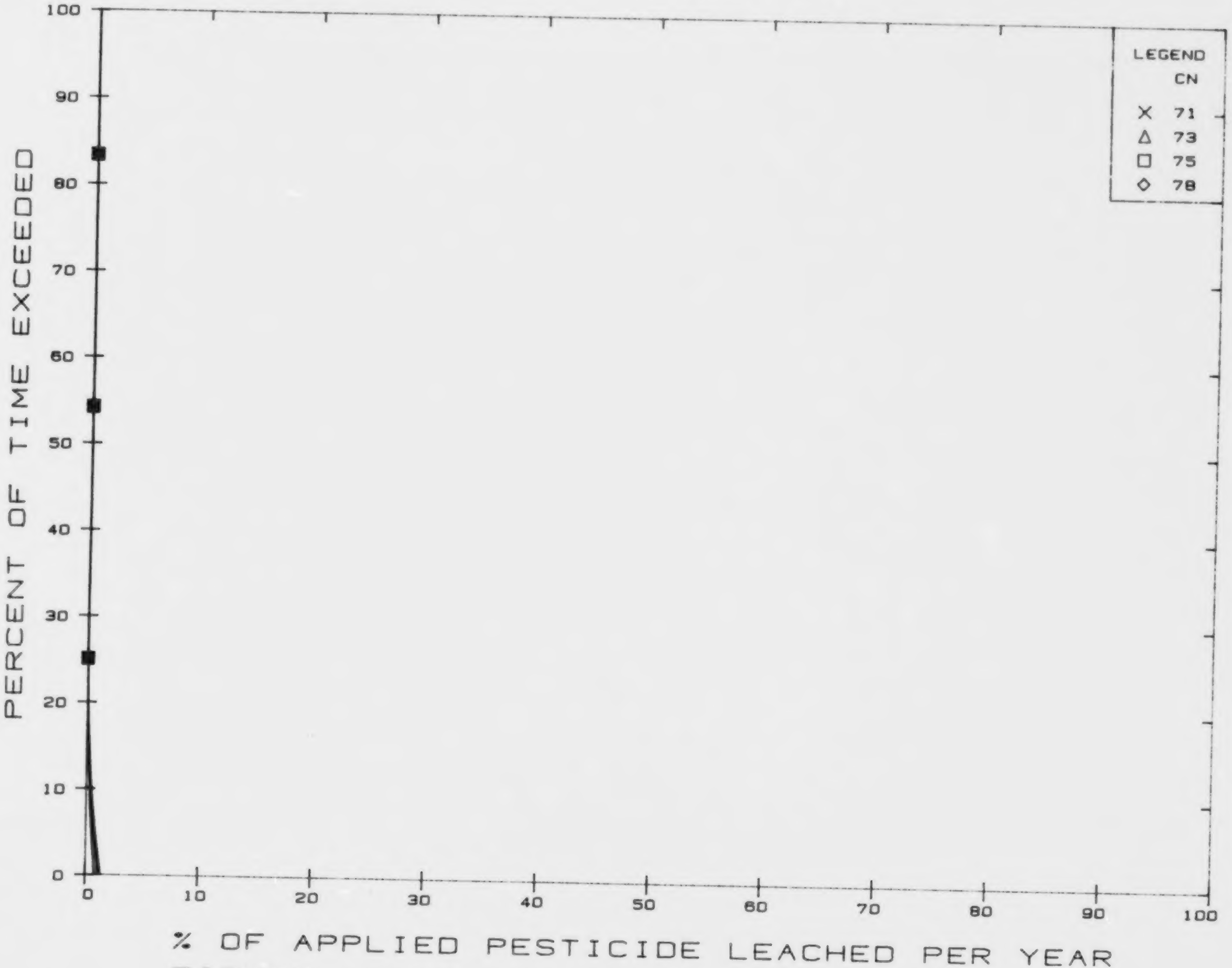


FIGURE A11-5 R=1. KS=.100

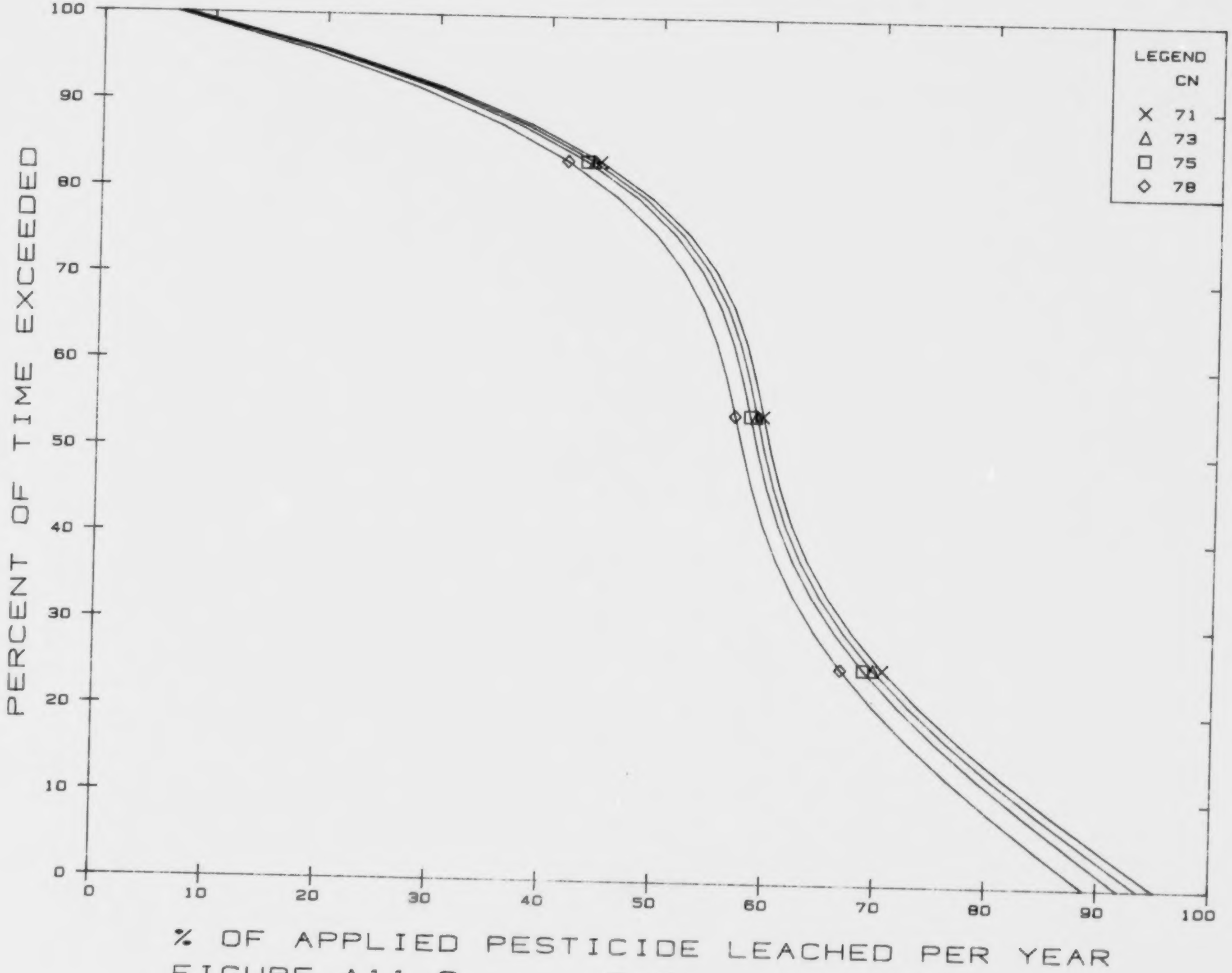


FIGURE A11-6 R=3. KS=.001

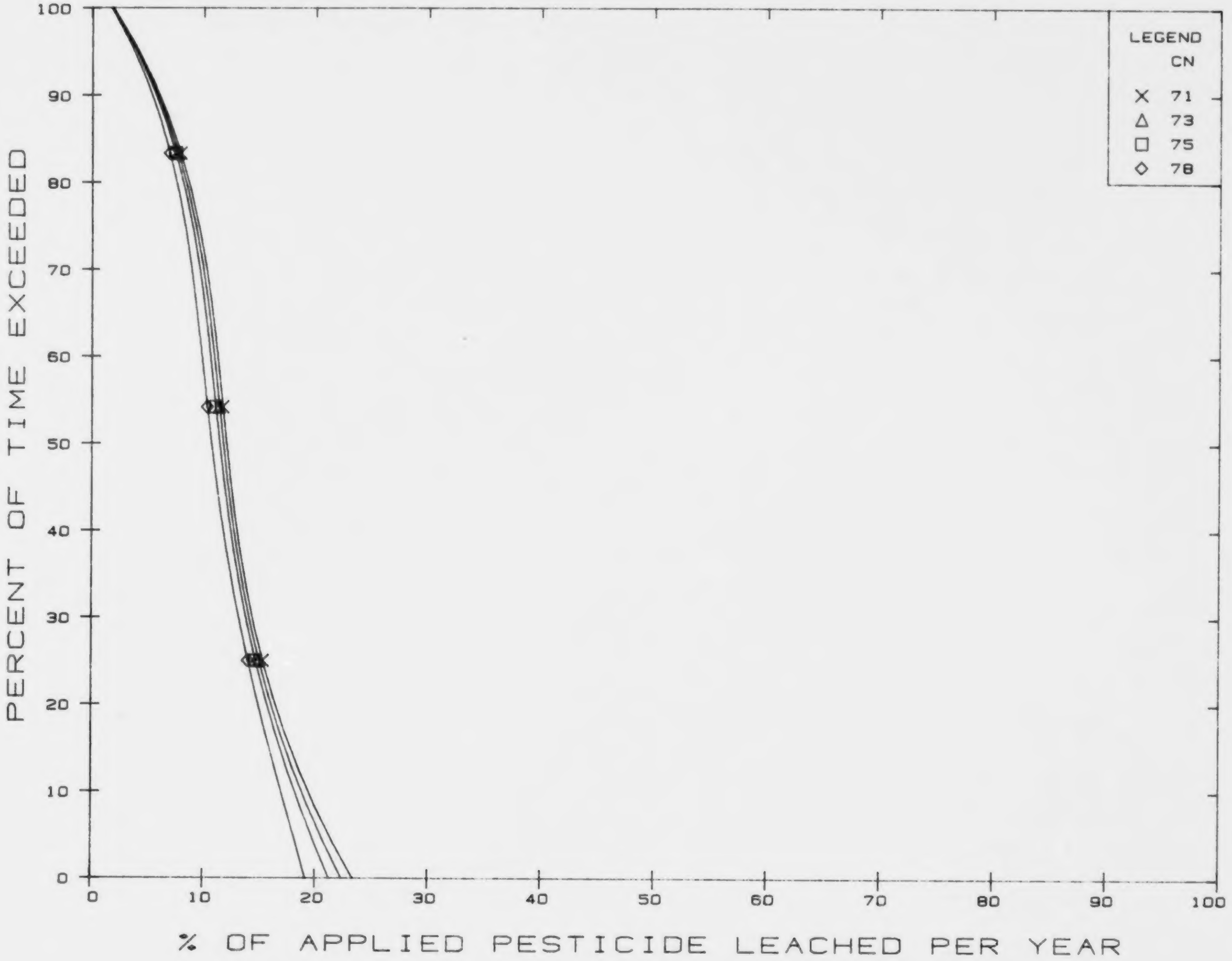


FIGURE A11-7 R=3. KS=.005

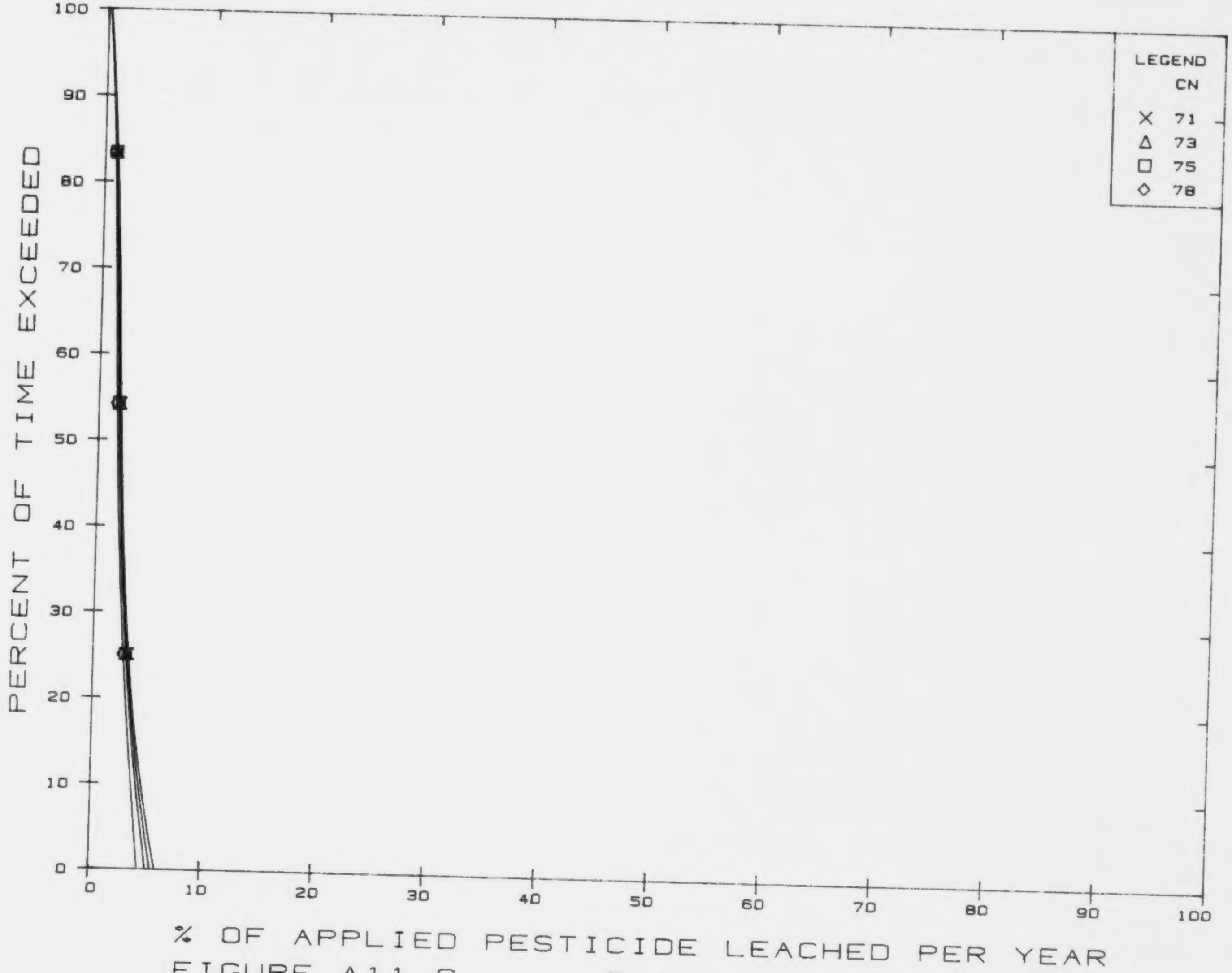


FIGURE A11-8 R=3. KS=.010

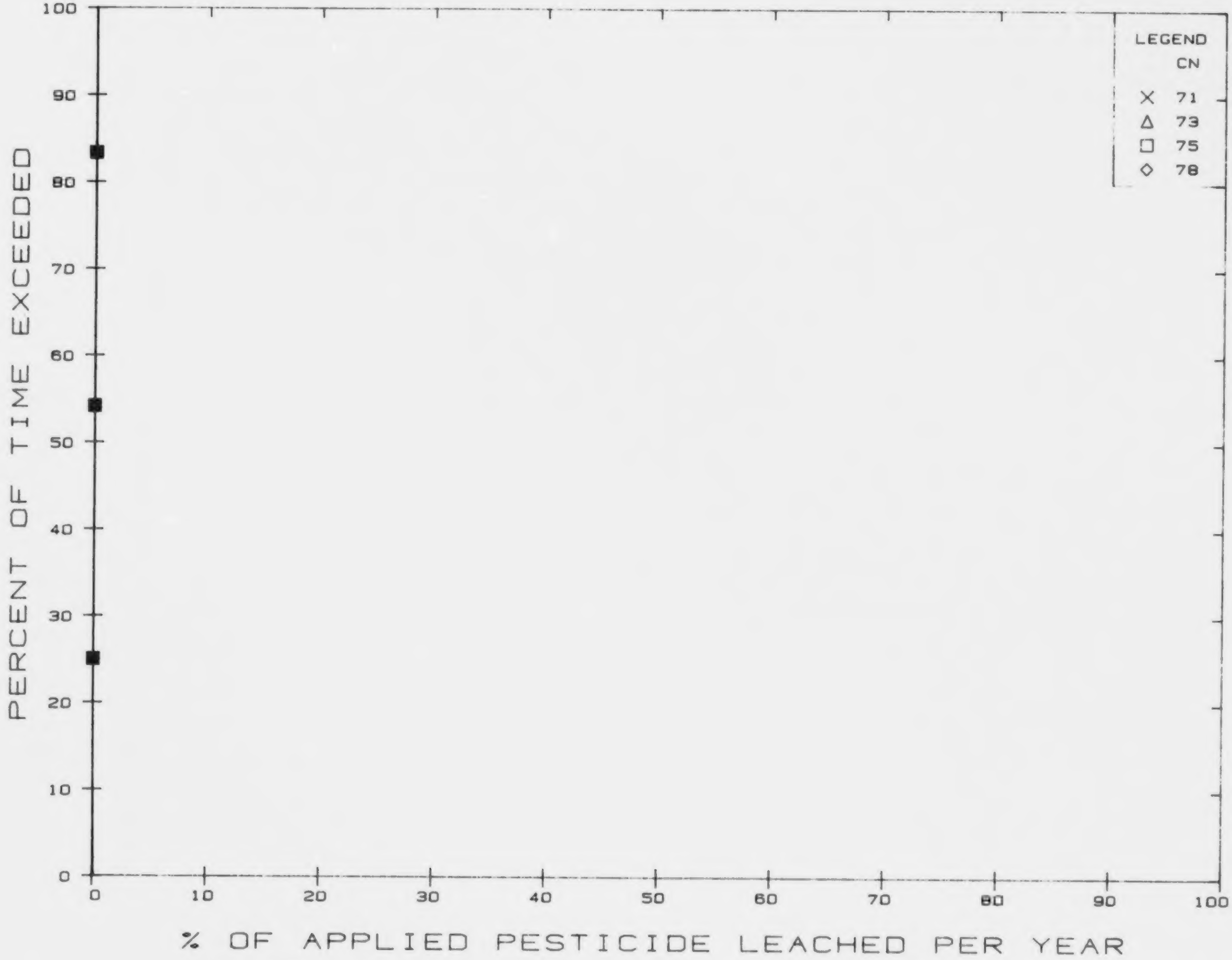


FIGURE A11-9 R=3. KS=.050

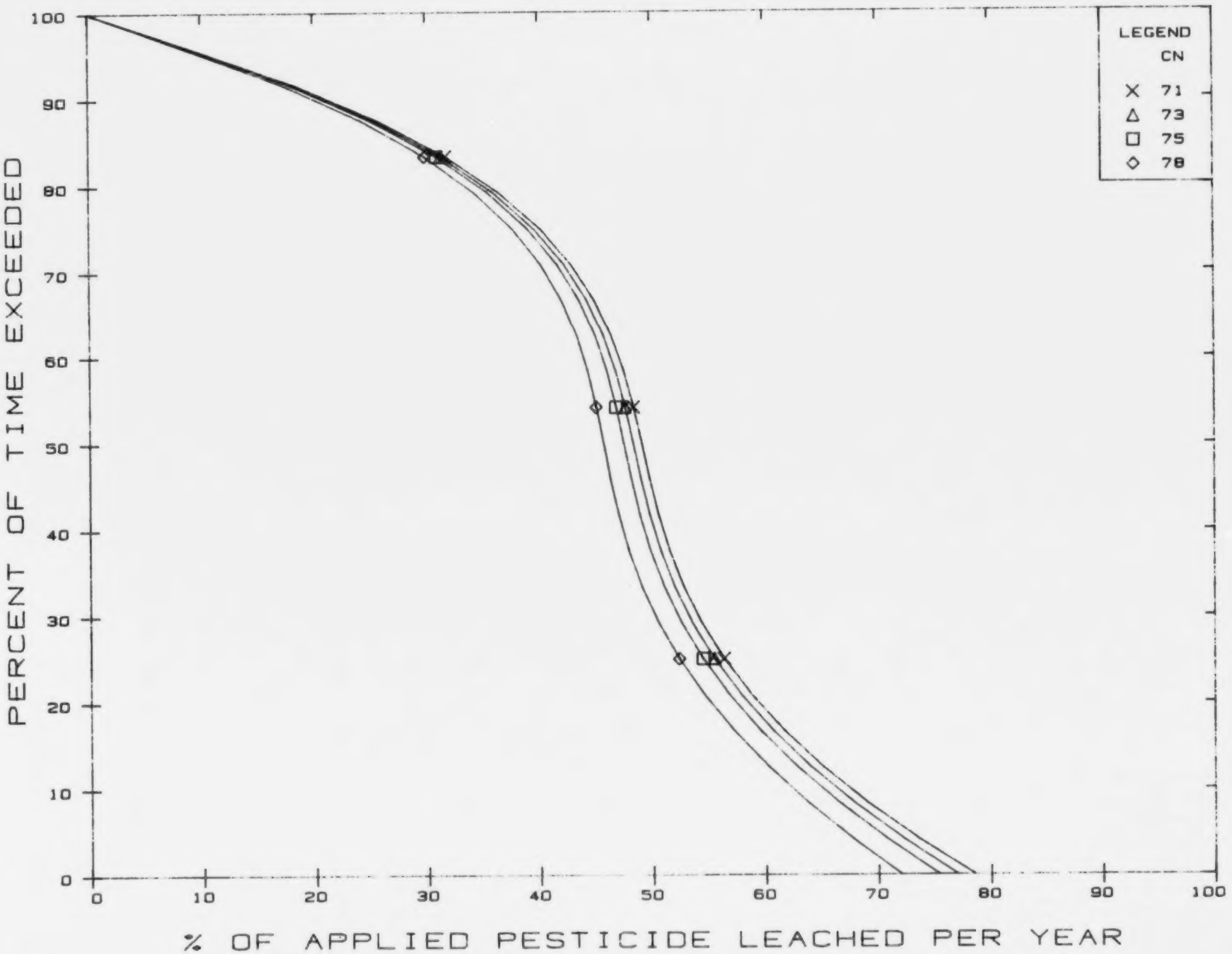


FIGURE A11-10 R=5. KS=.001

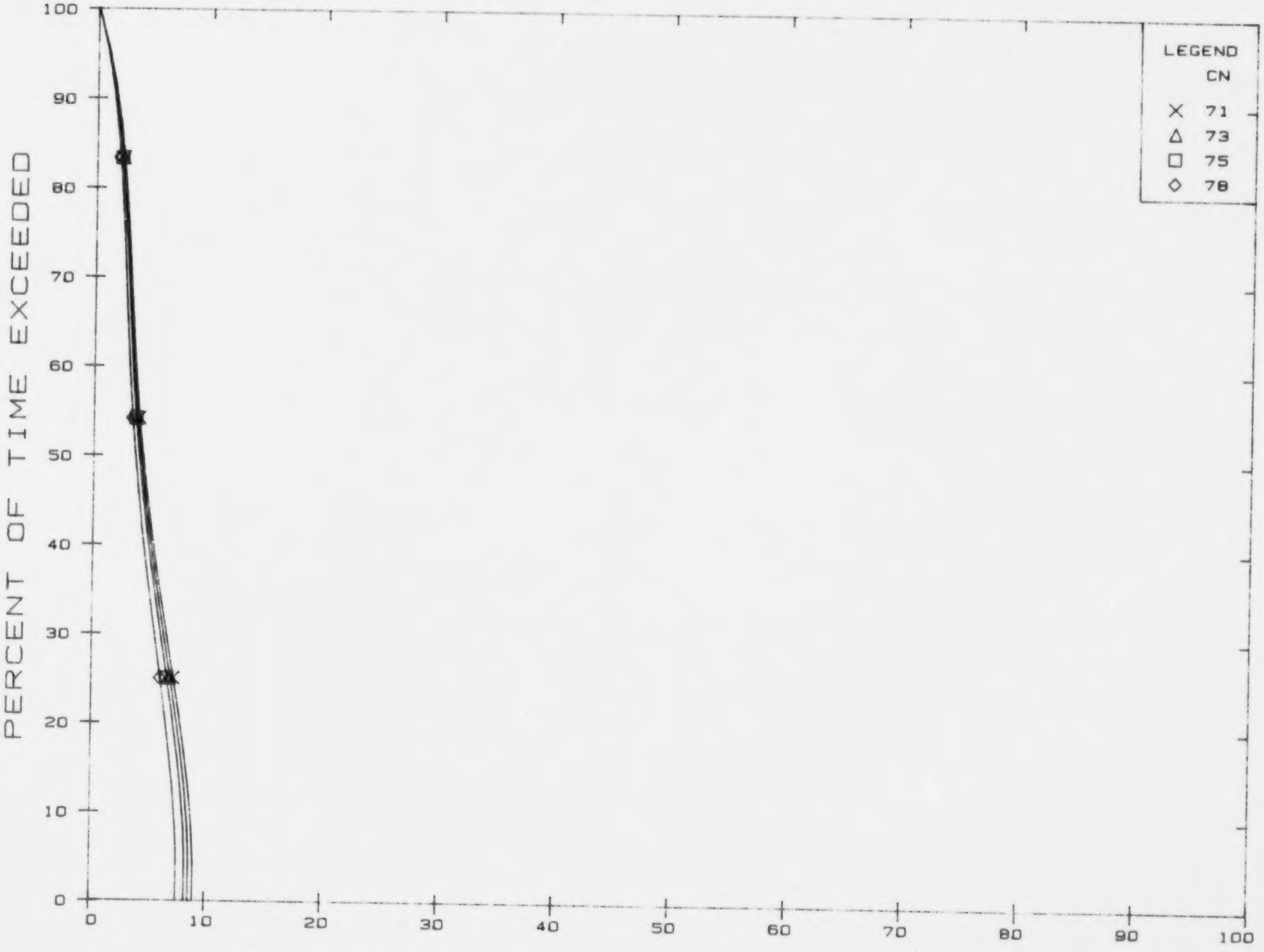


FIGURE A11-11 R=5. KS=.005

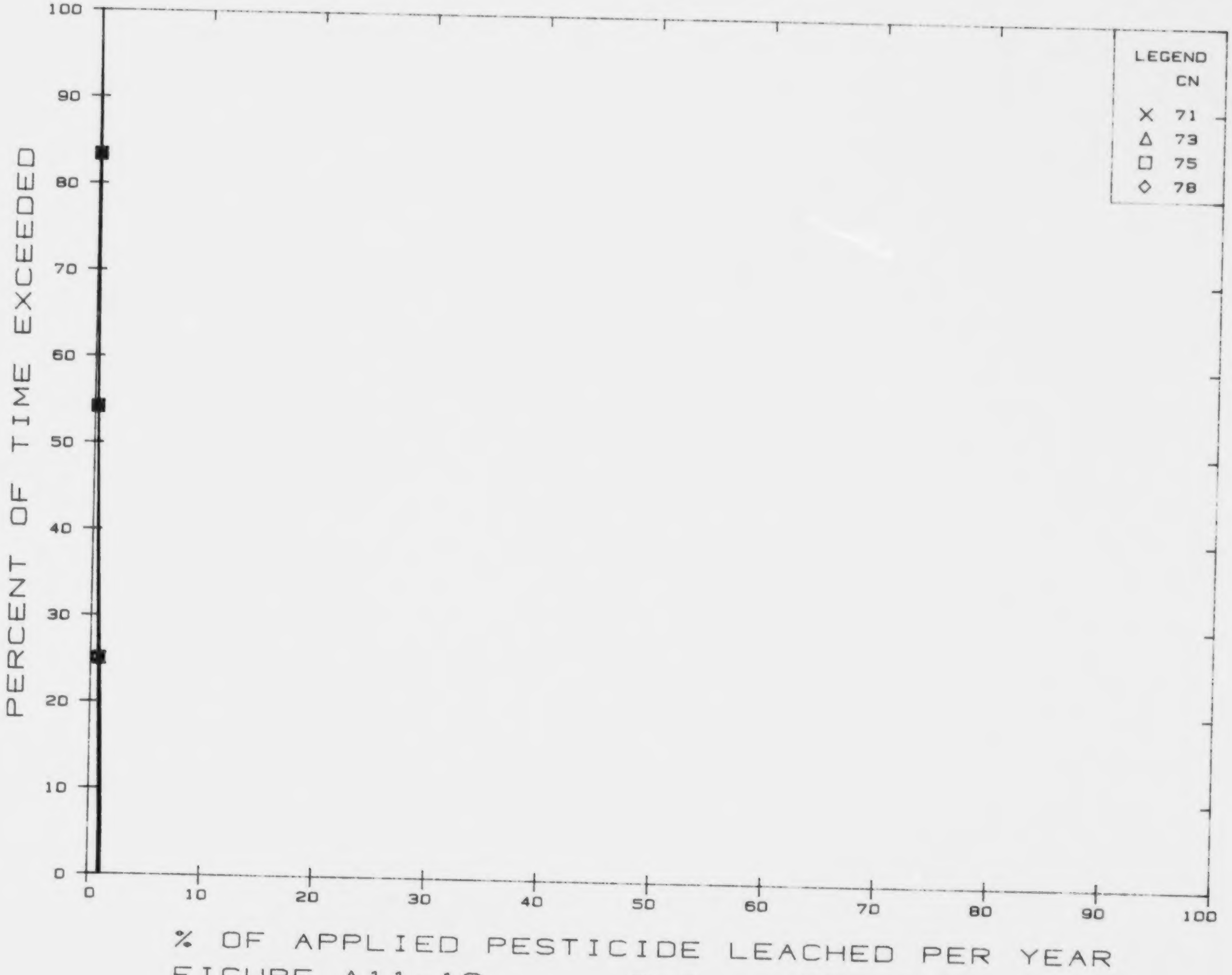


FIGURE A11-12 R=5. KS=.010

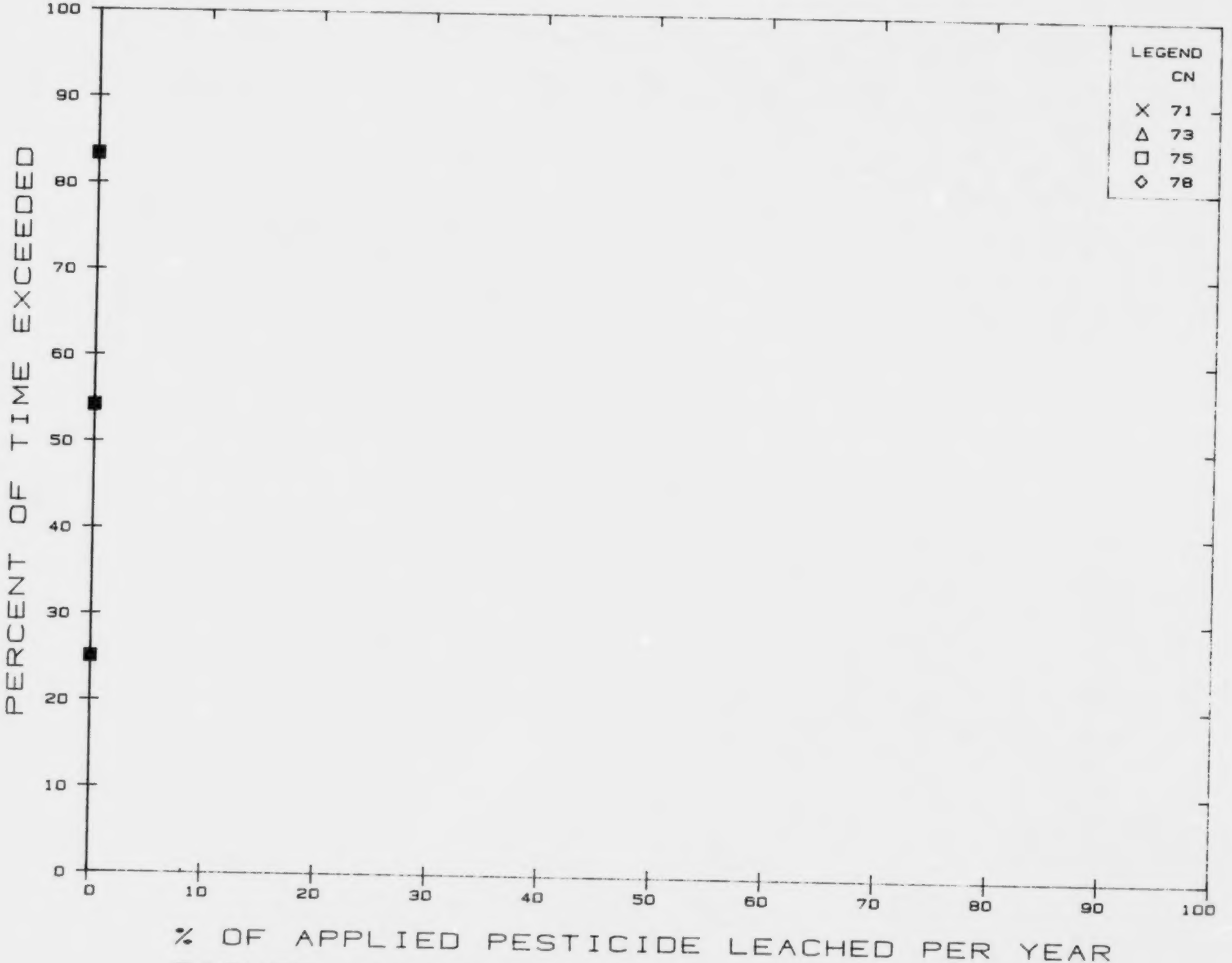


FIGURE A11-13 R=5. KS=.050

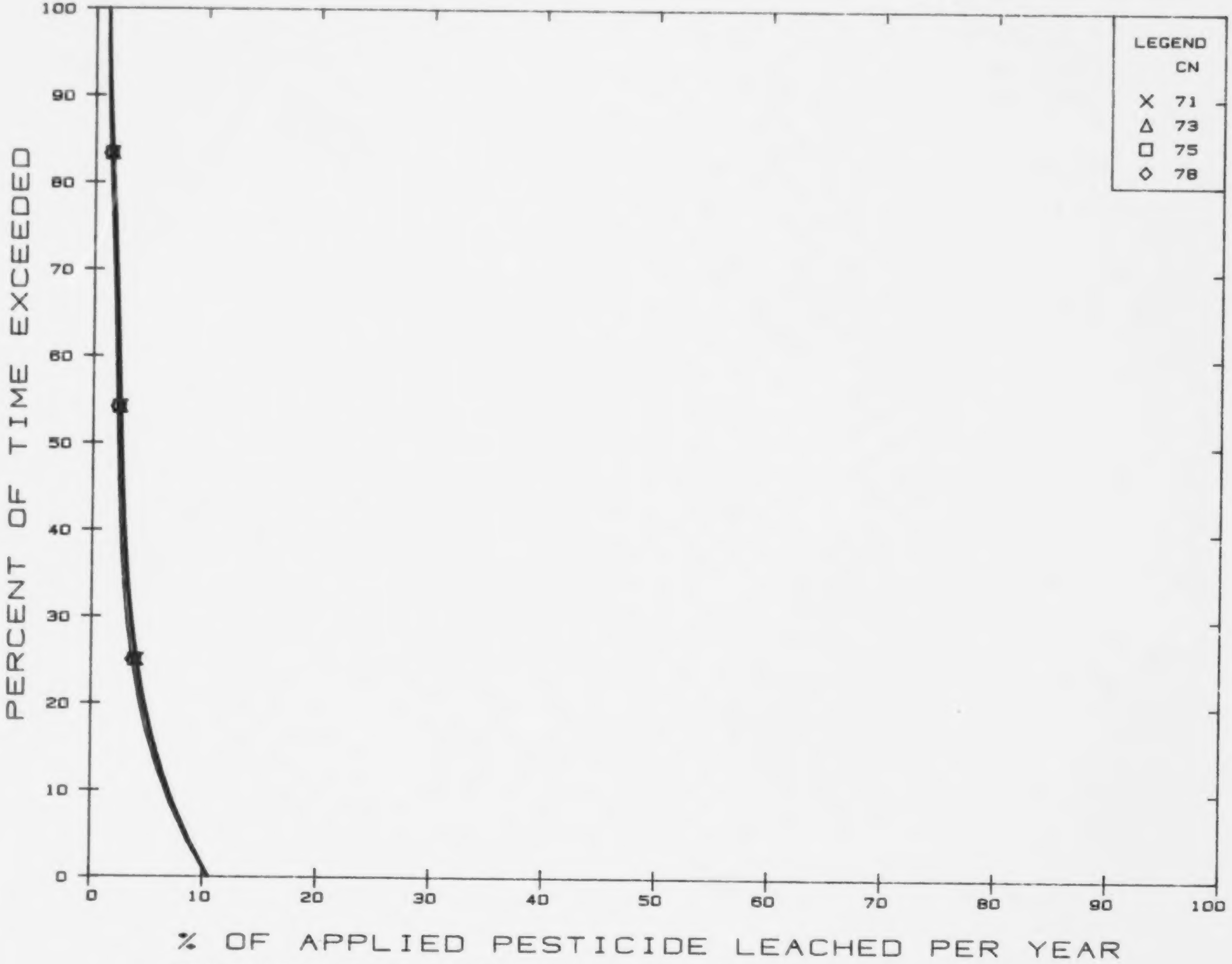


FIGURE A11-14 R=20. KS=.001

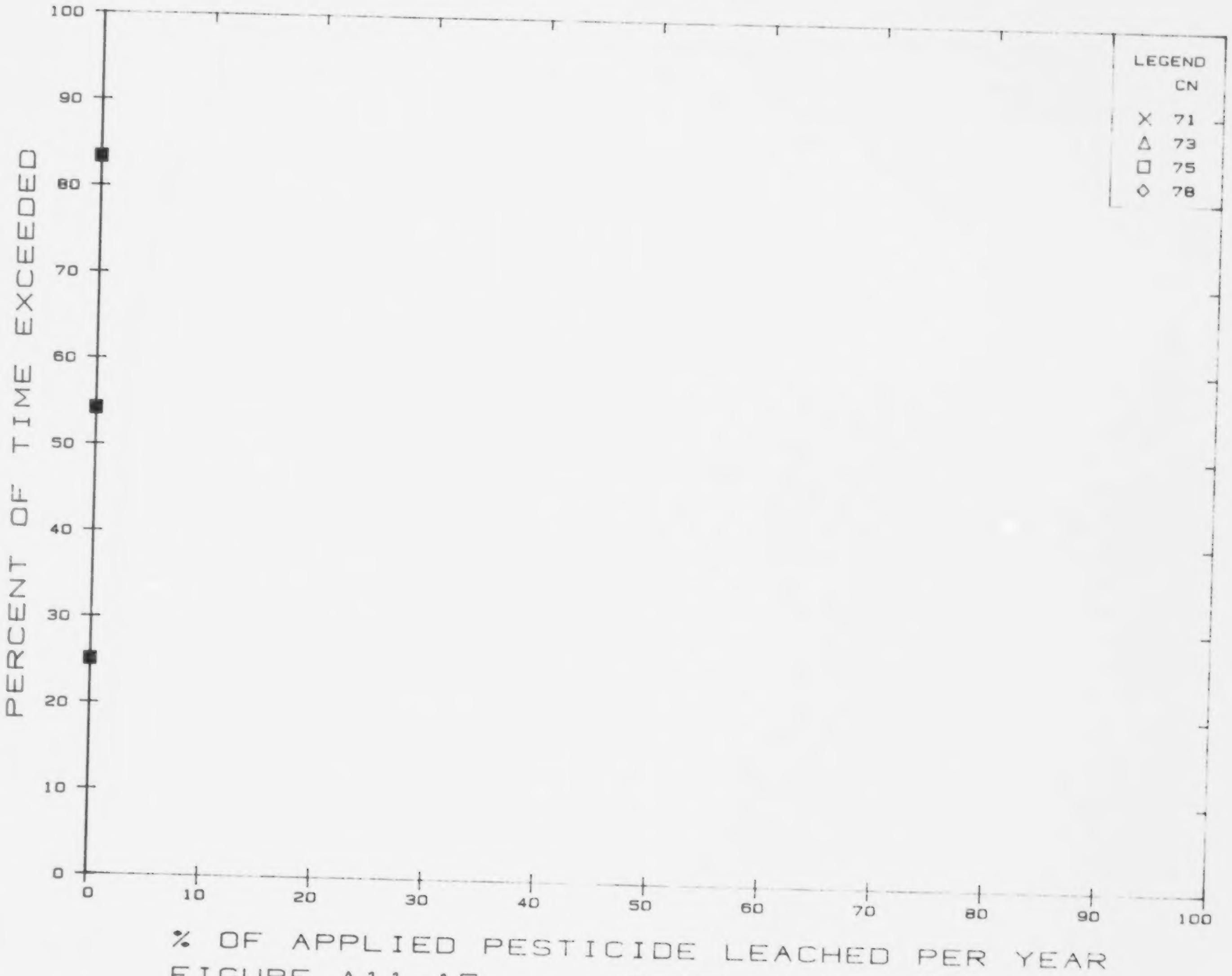


FIGURE A11-15 R=20. KS=.005

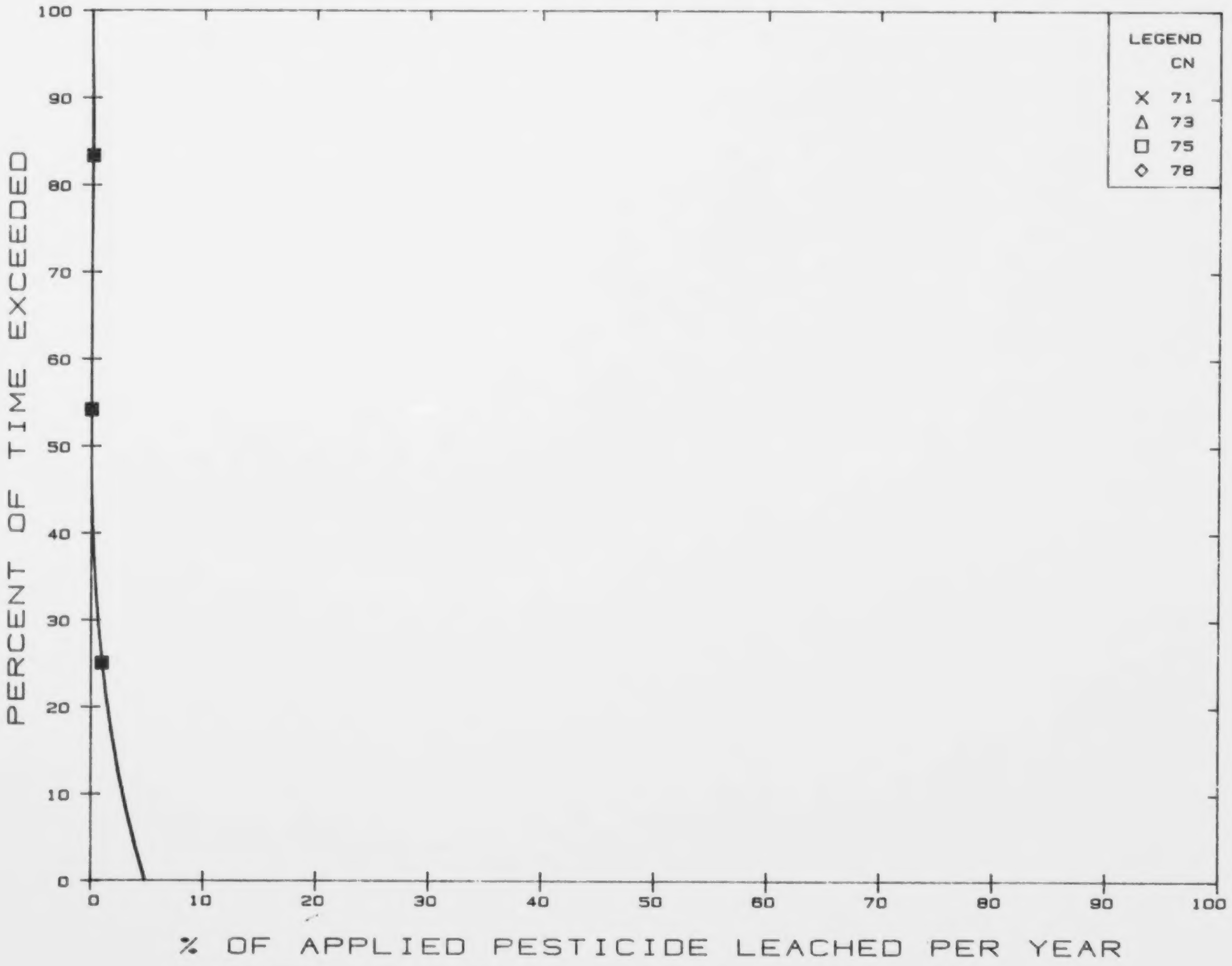


FIGURE A11-16 R=50. KS=.001

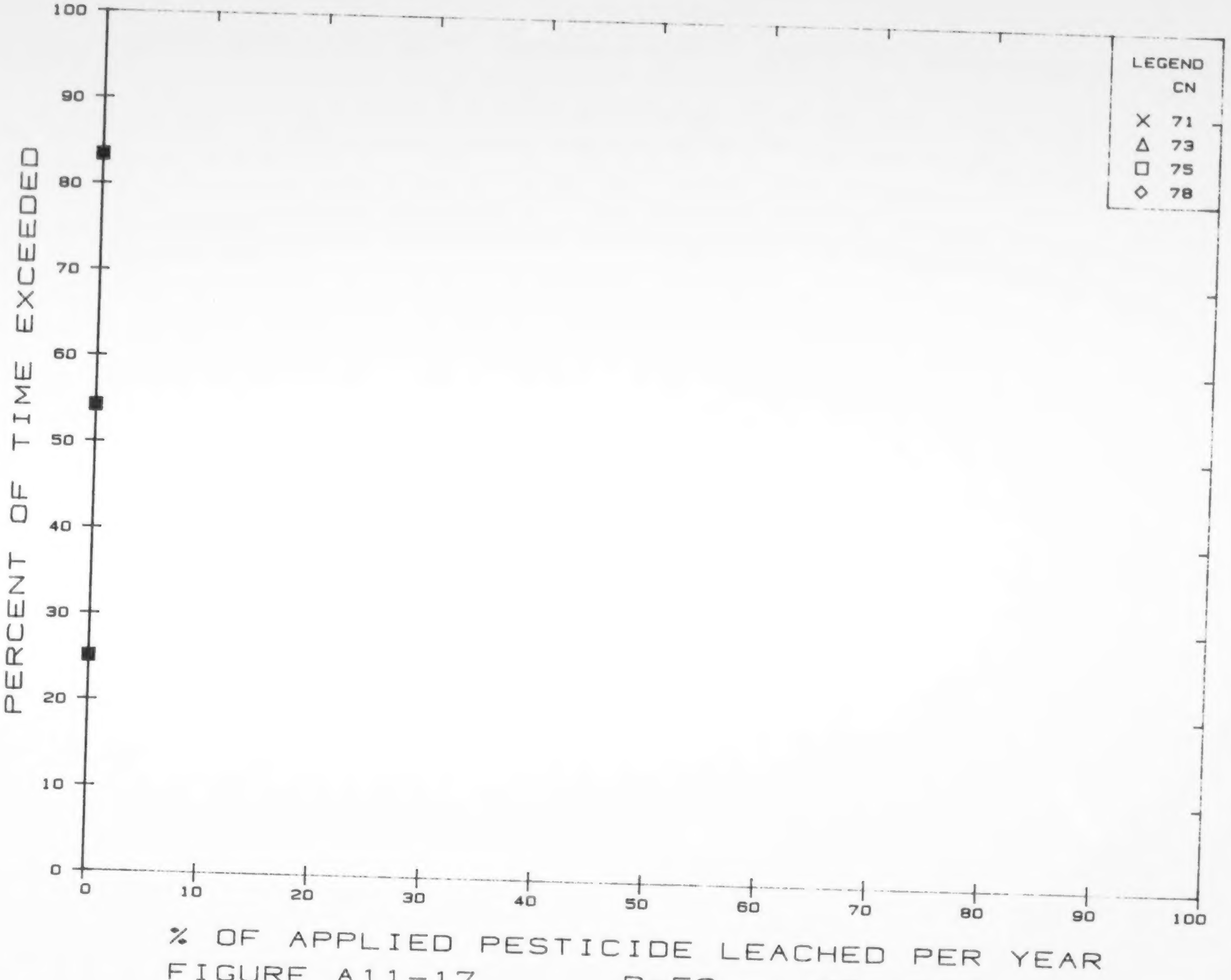


FIGURE A11-17 R=50. KS=.005

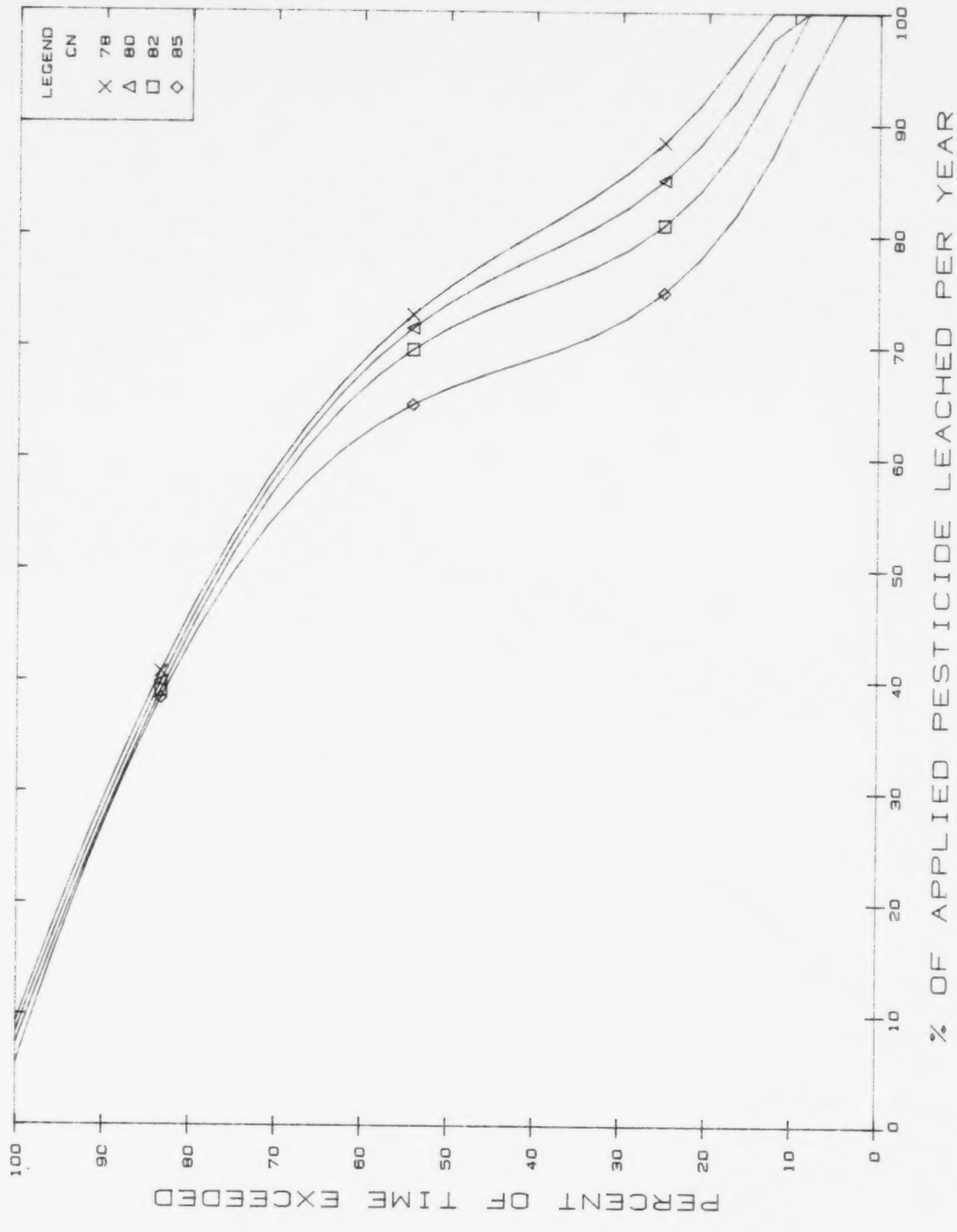


FIGURE A12-1 R=1. KS=.001

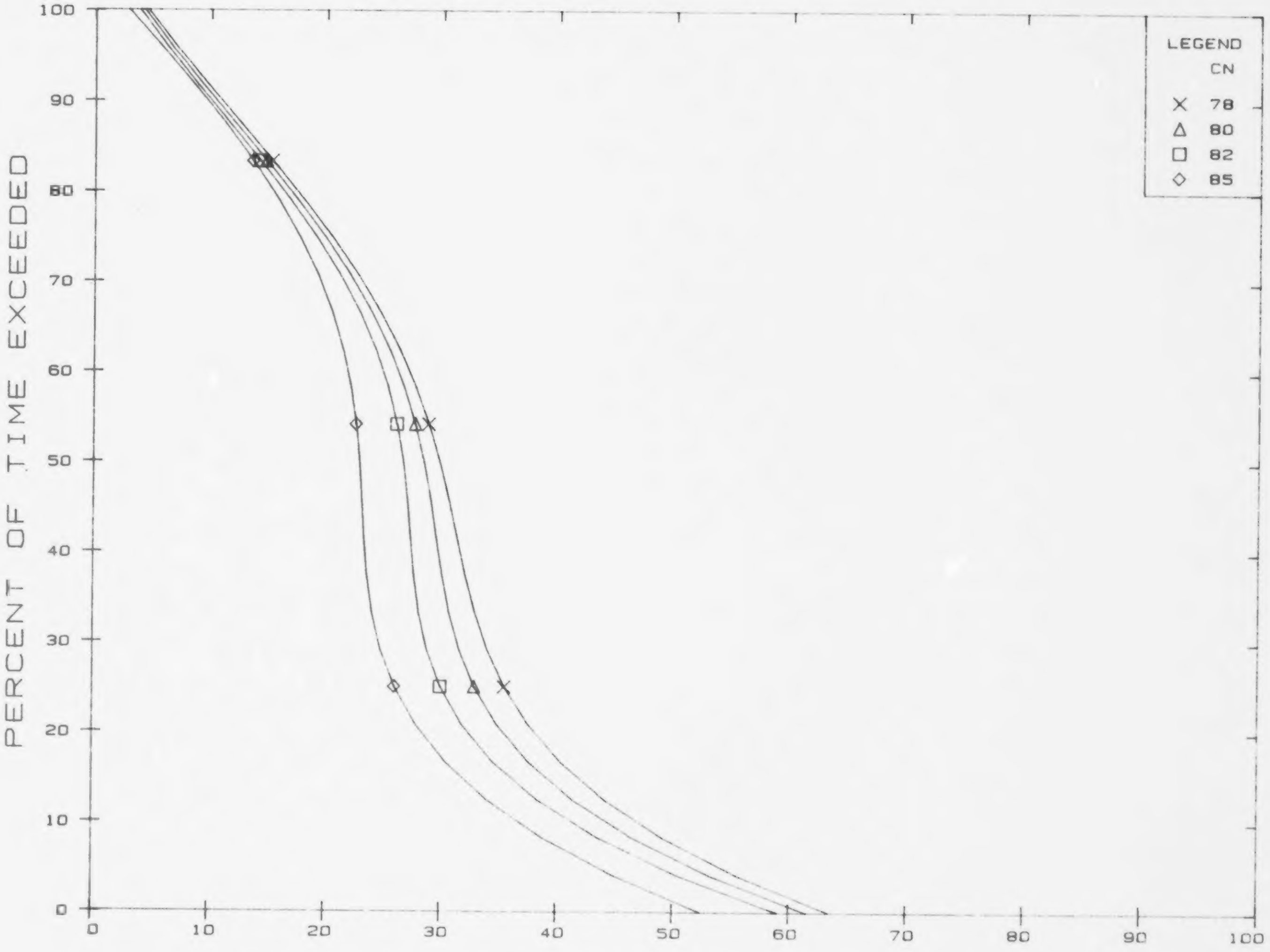


FIGURE A12-2 R=1. KS=.005

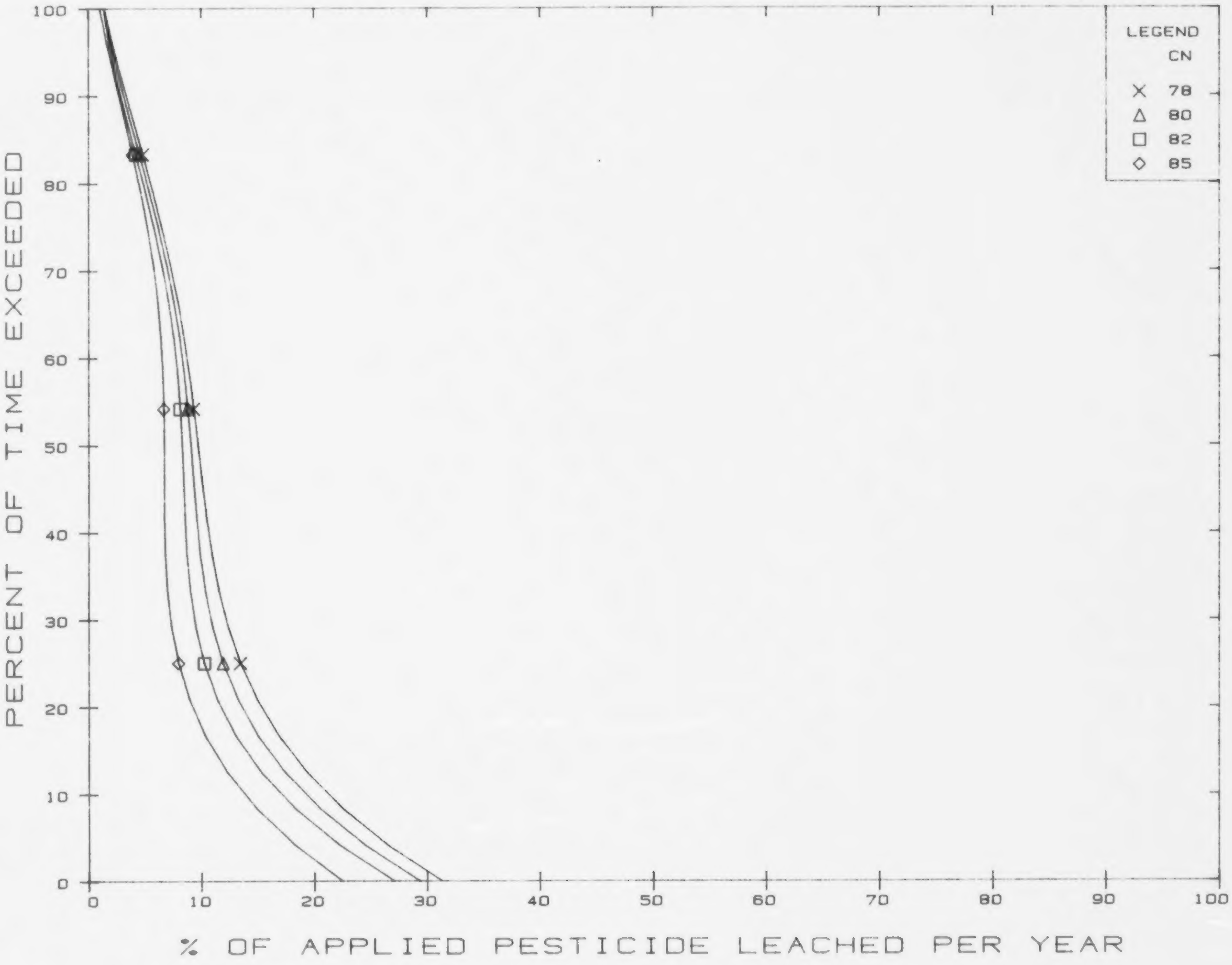


FIGURE A12-3 R=1. KS=.010

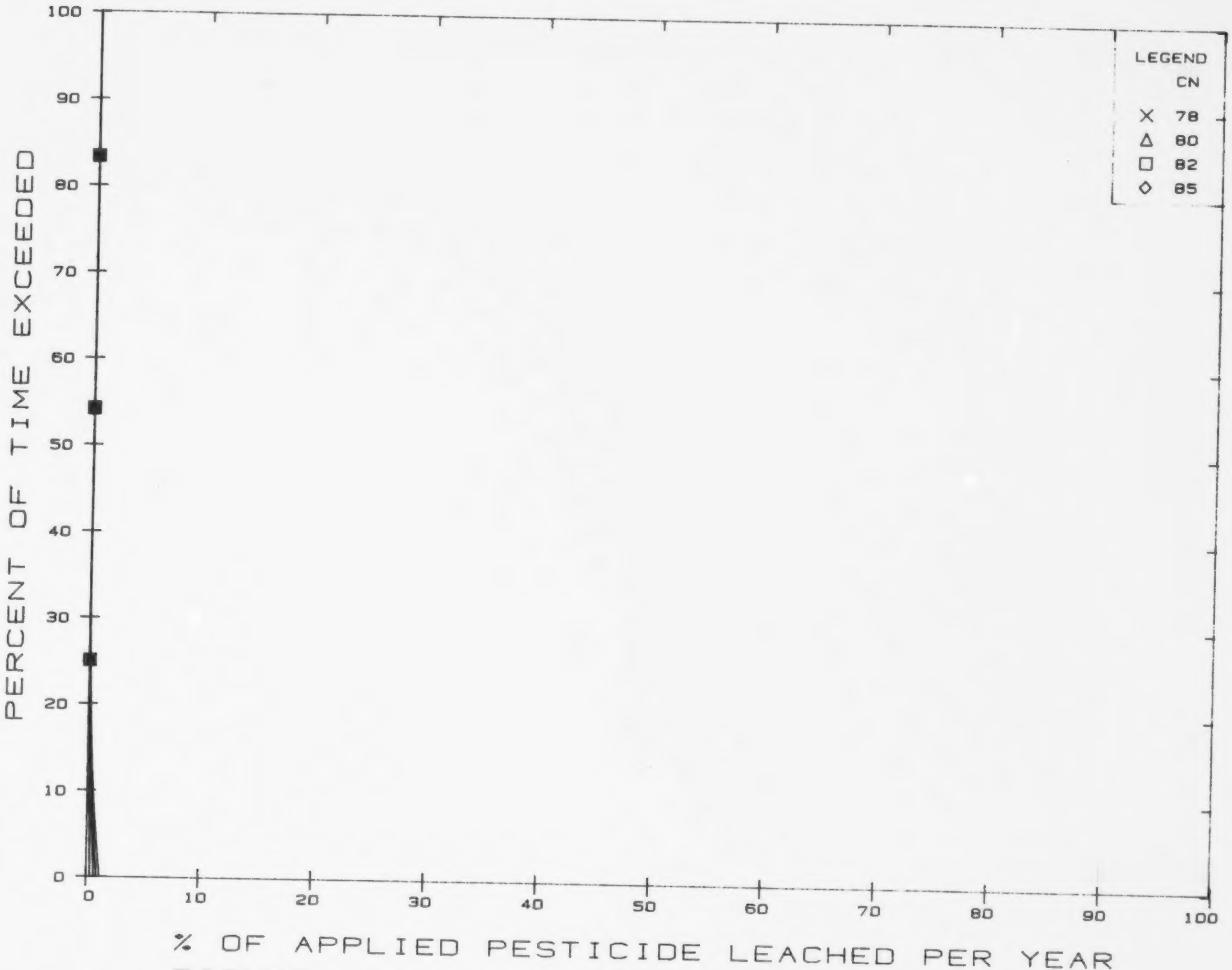


FIGURE A12-4 R=1. KS=.050

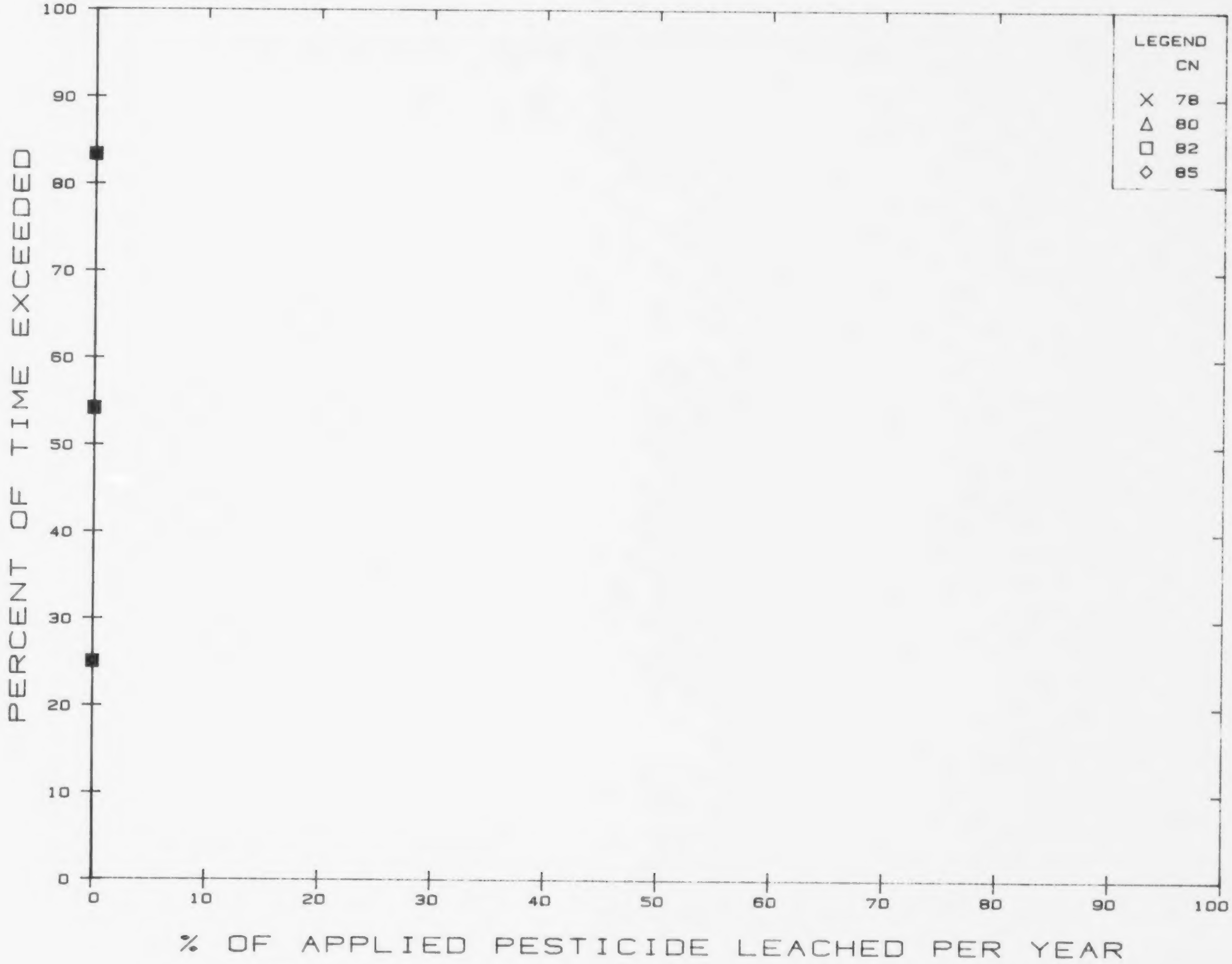


FIGURE A12-5 R=1. KS=.100

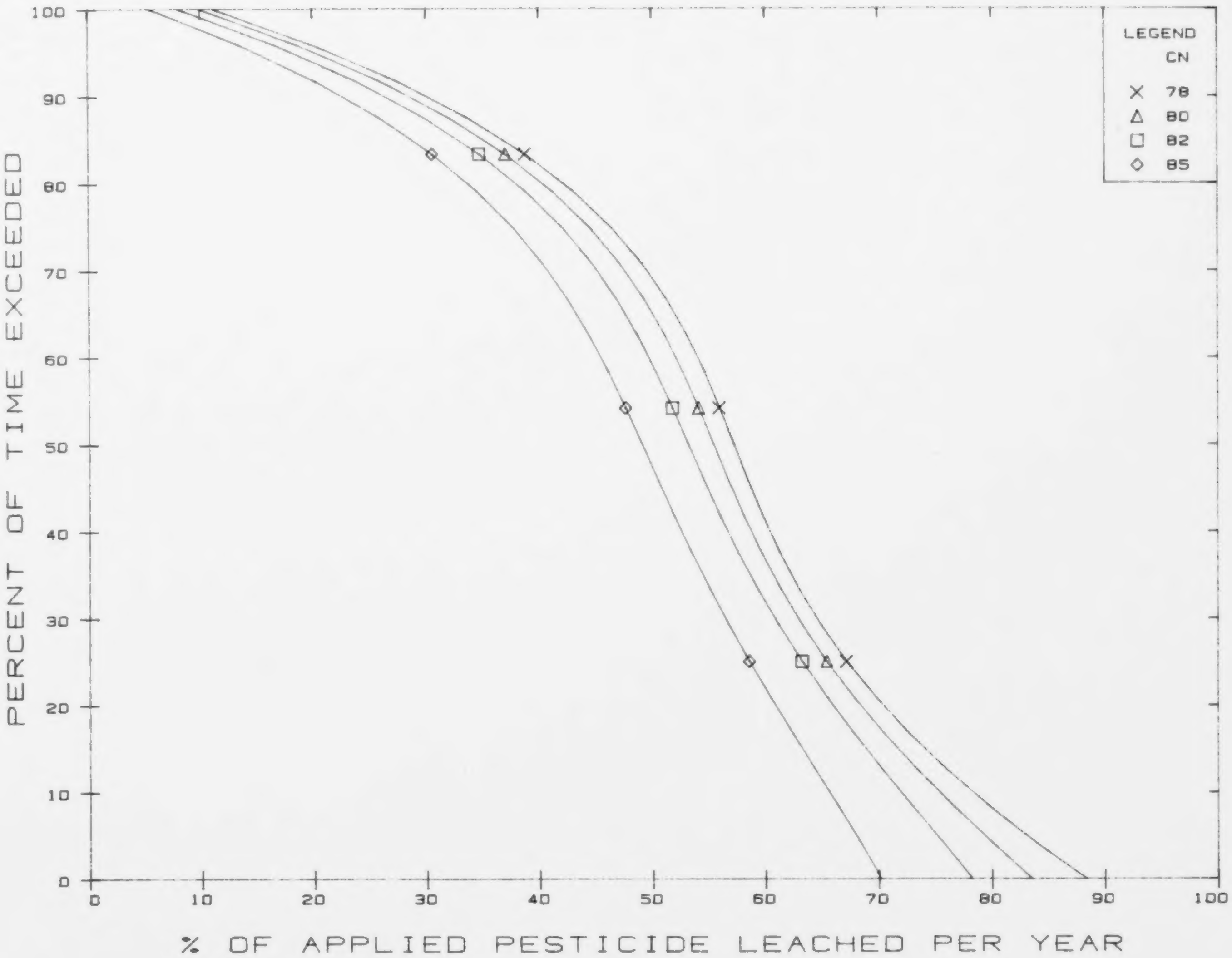


FIGURE A12-6 R=3. KS=.001

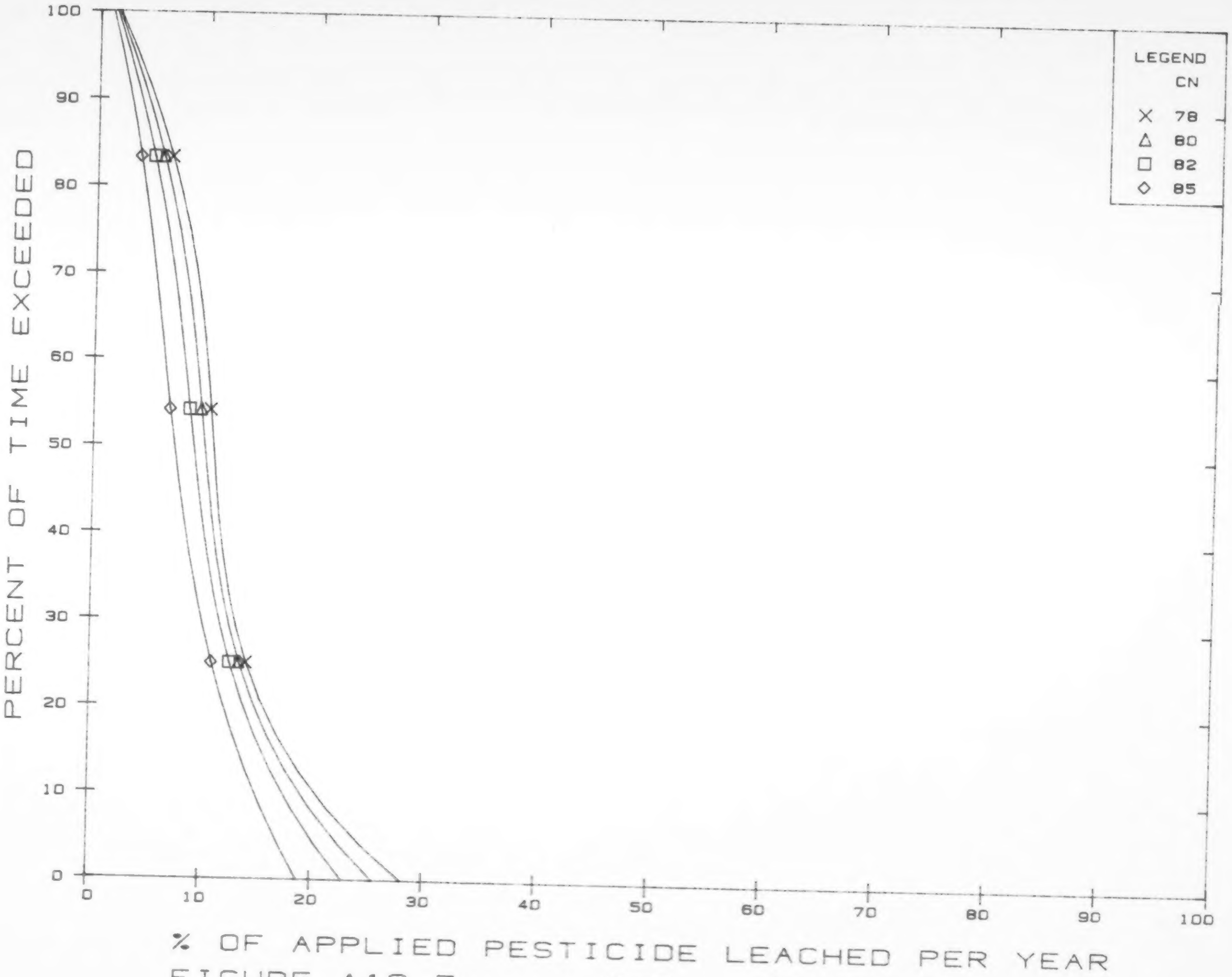


FIGURE A12-7 R=3. KS=.005

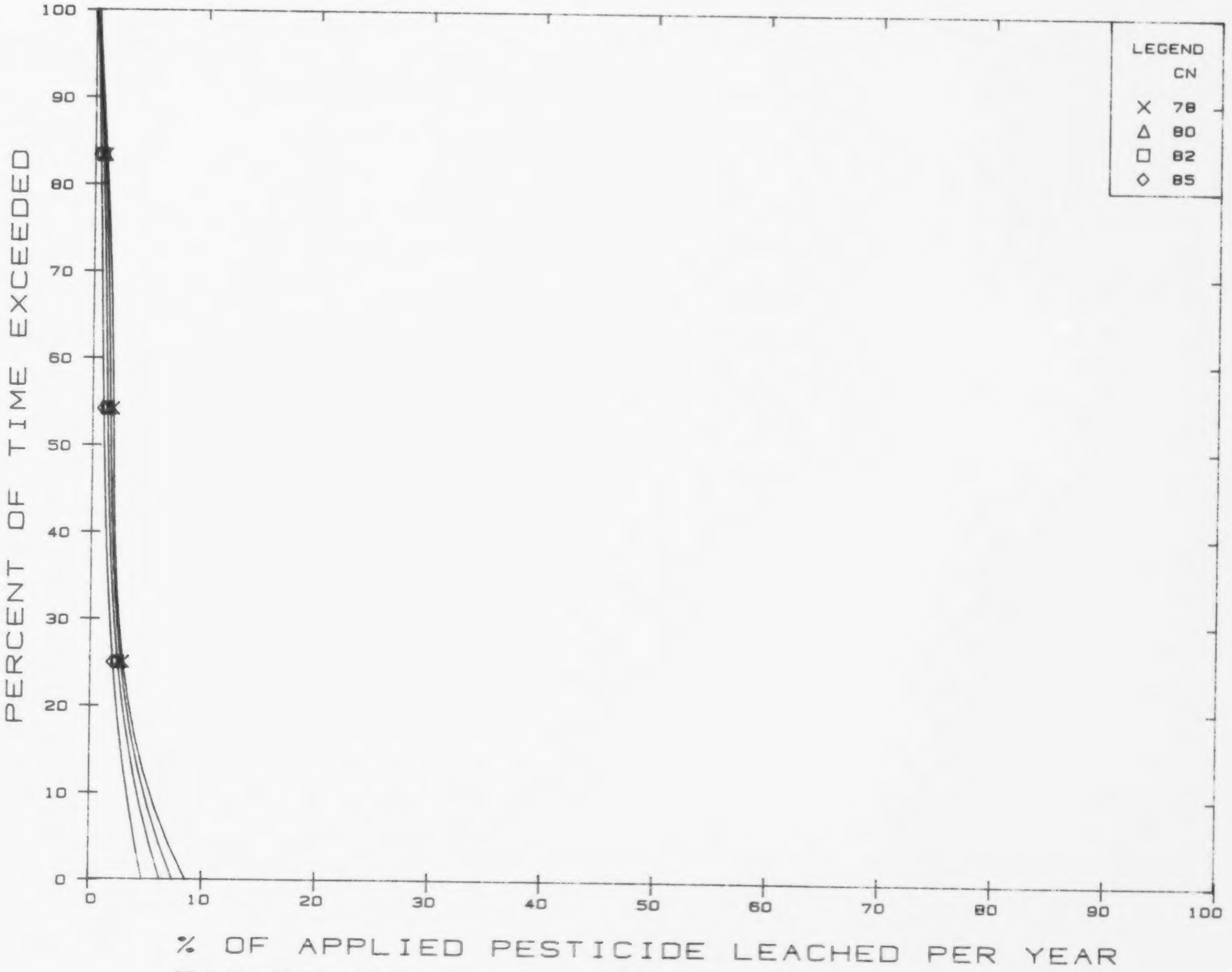


FIGURE A12-8 R=3. KS=.010

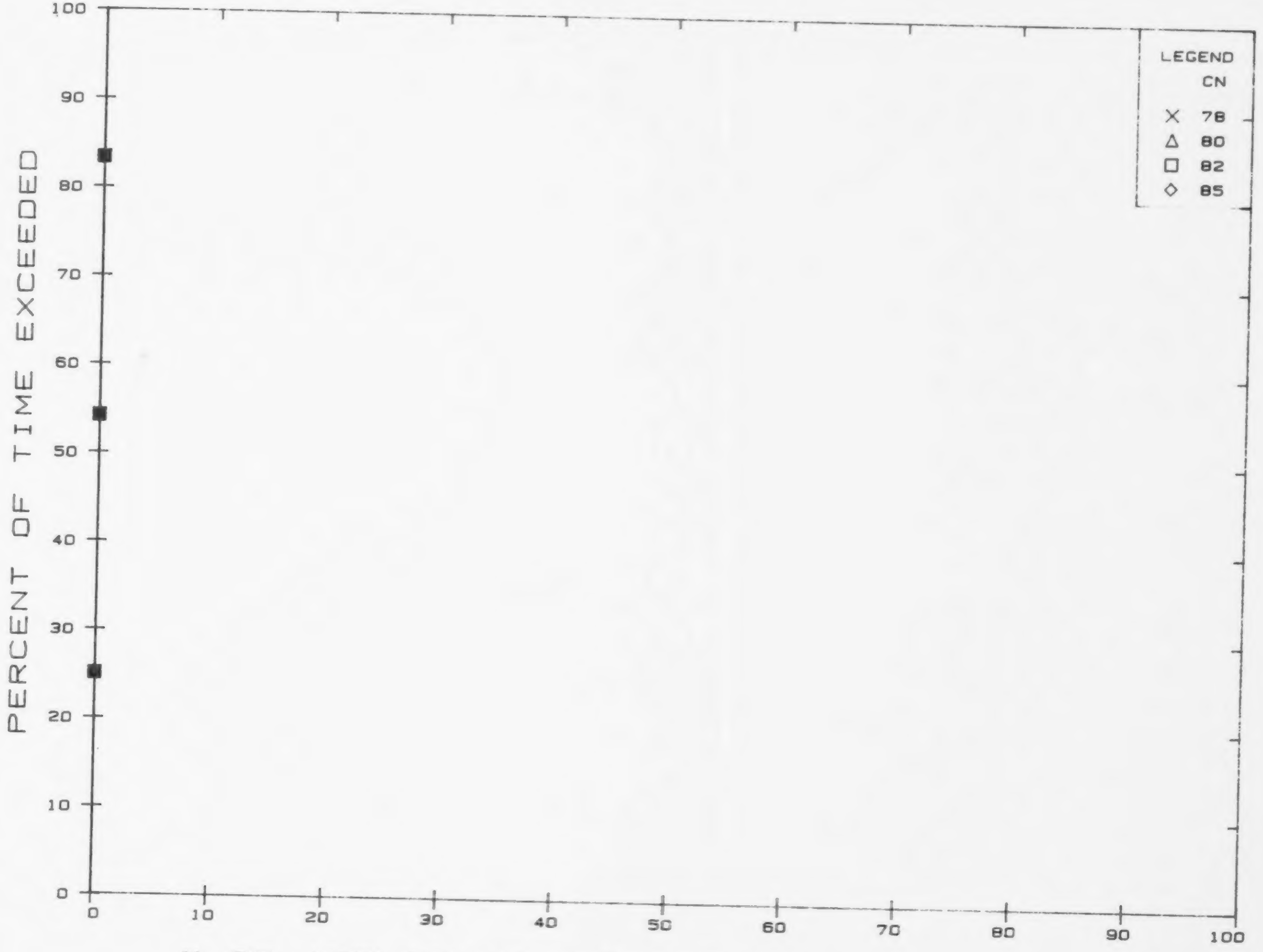


FIGURE A12-9 R=3. KS=.050

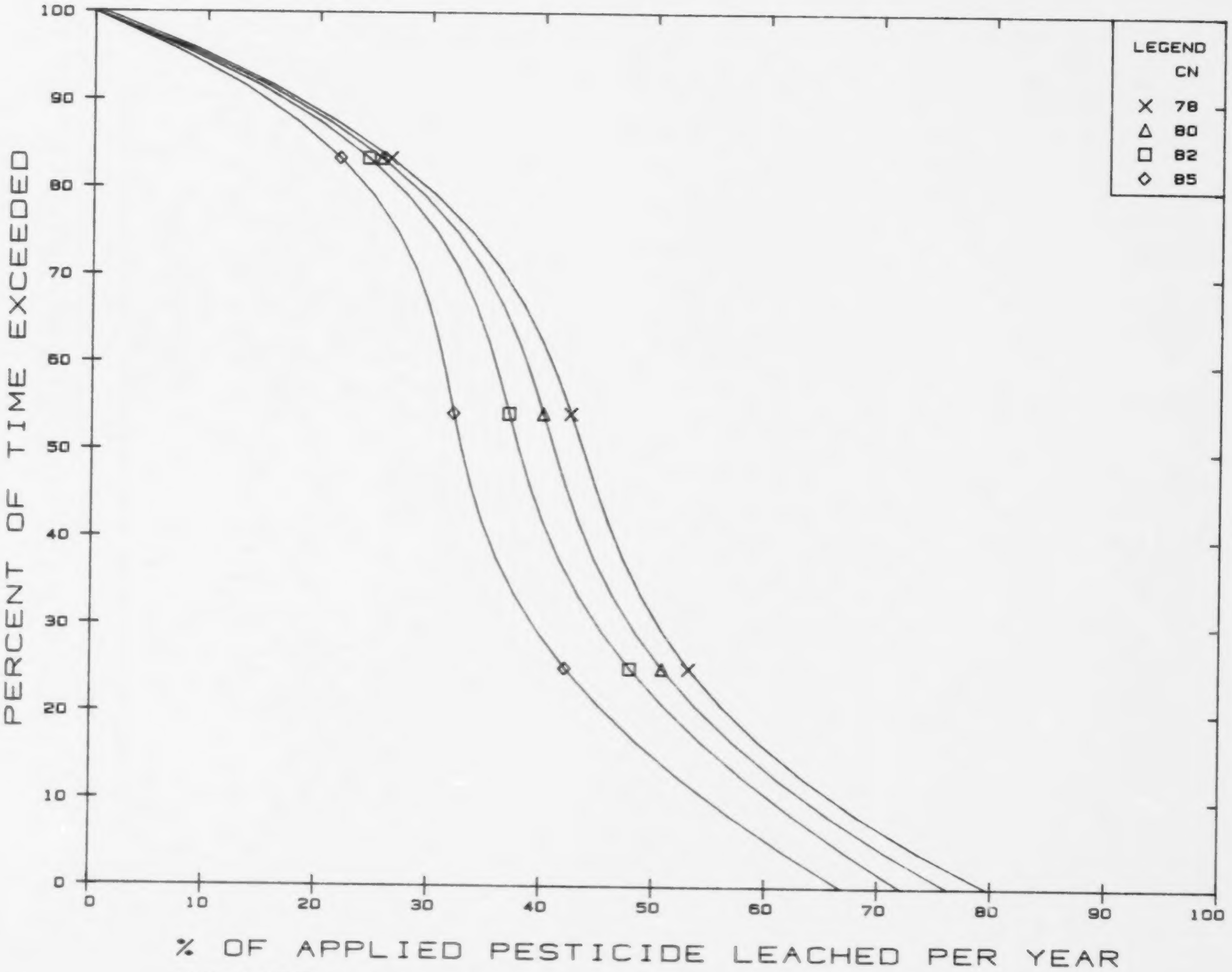


FIGURE A12-10 R=5. KS=.001

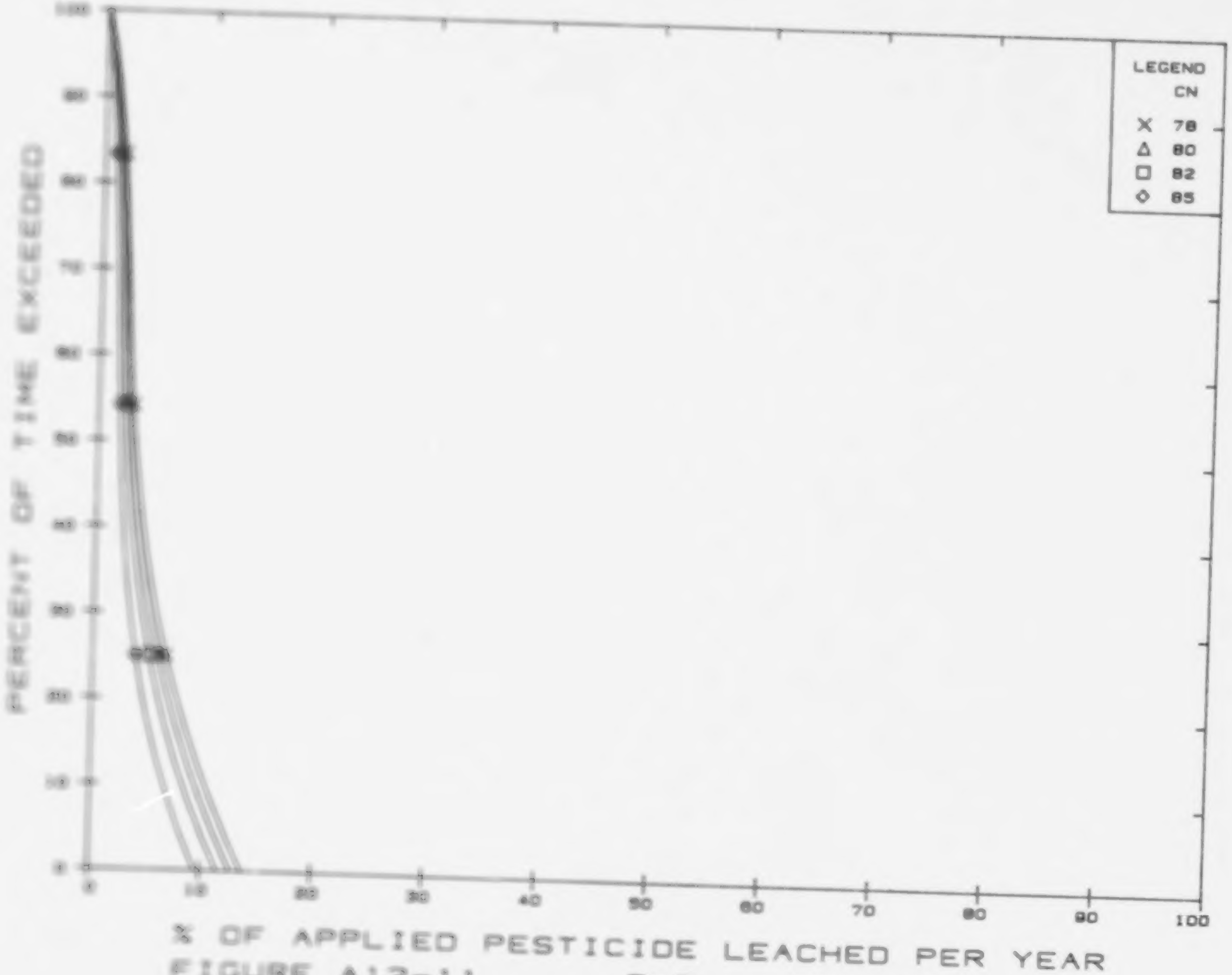
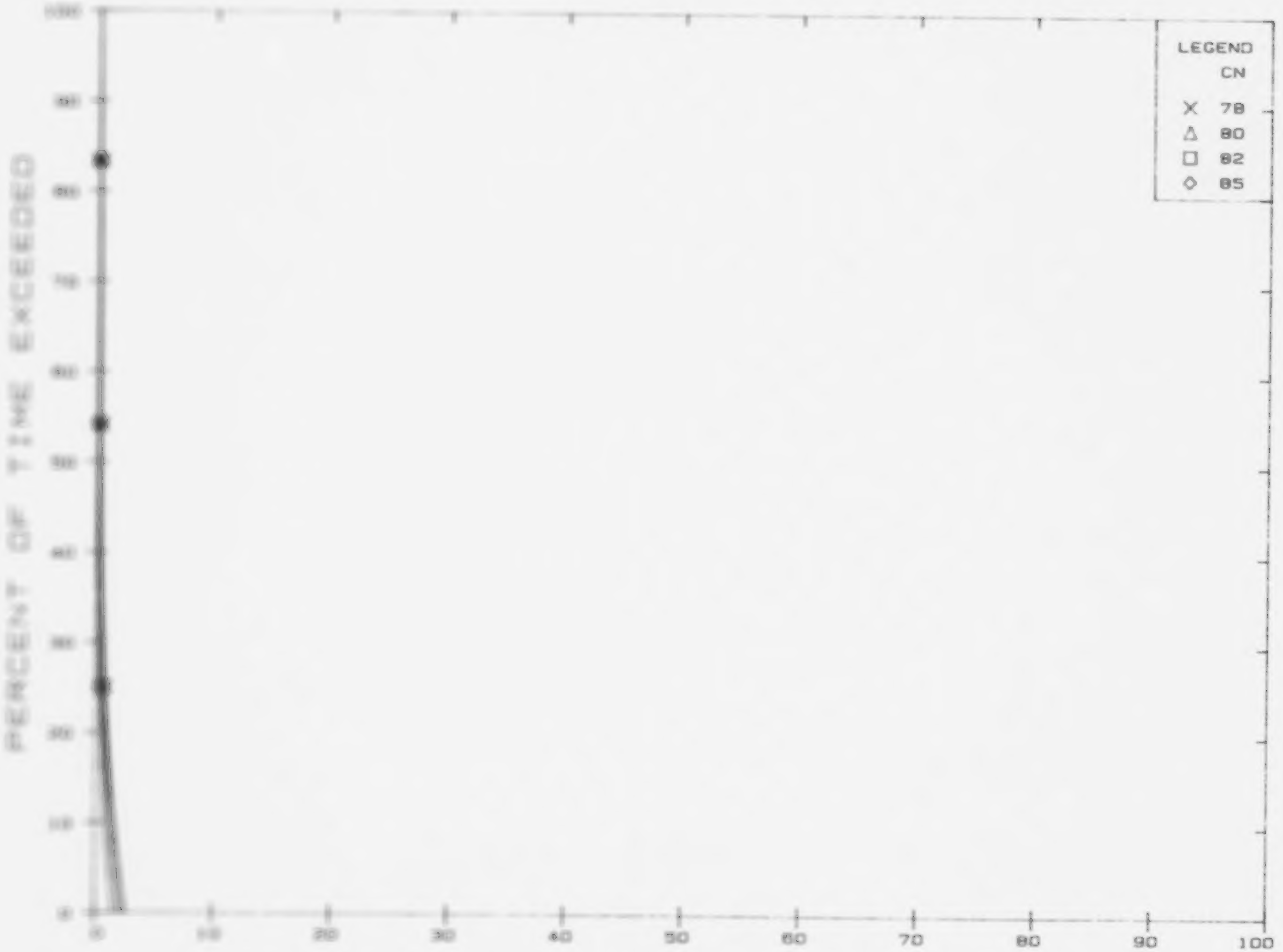
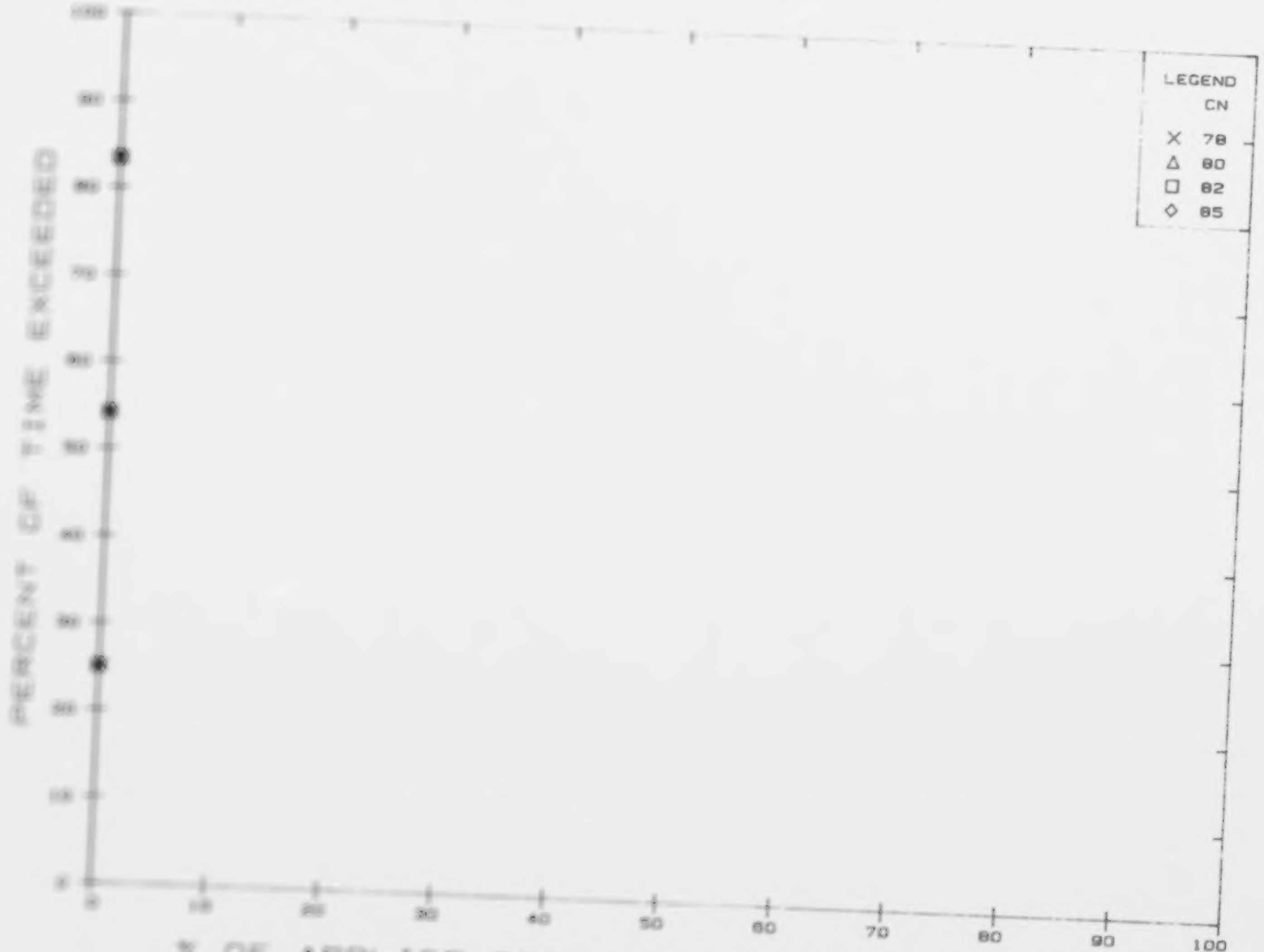


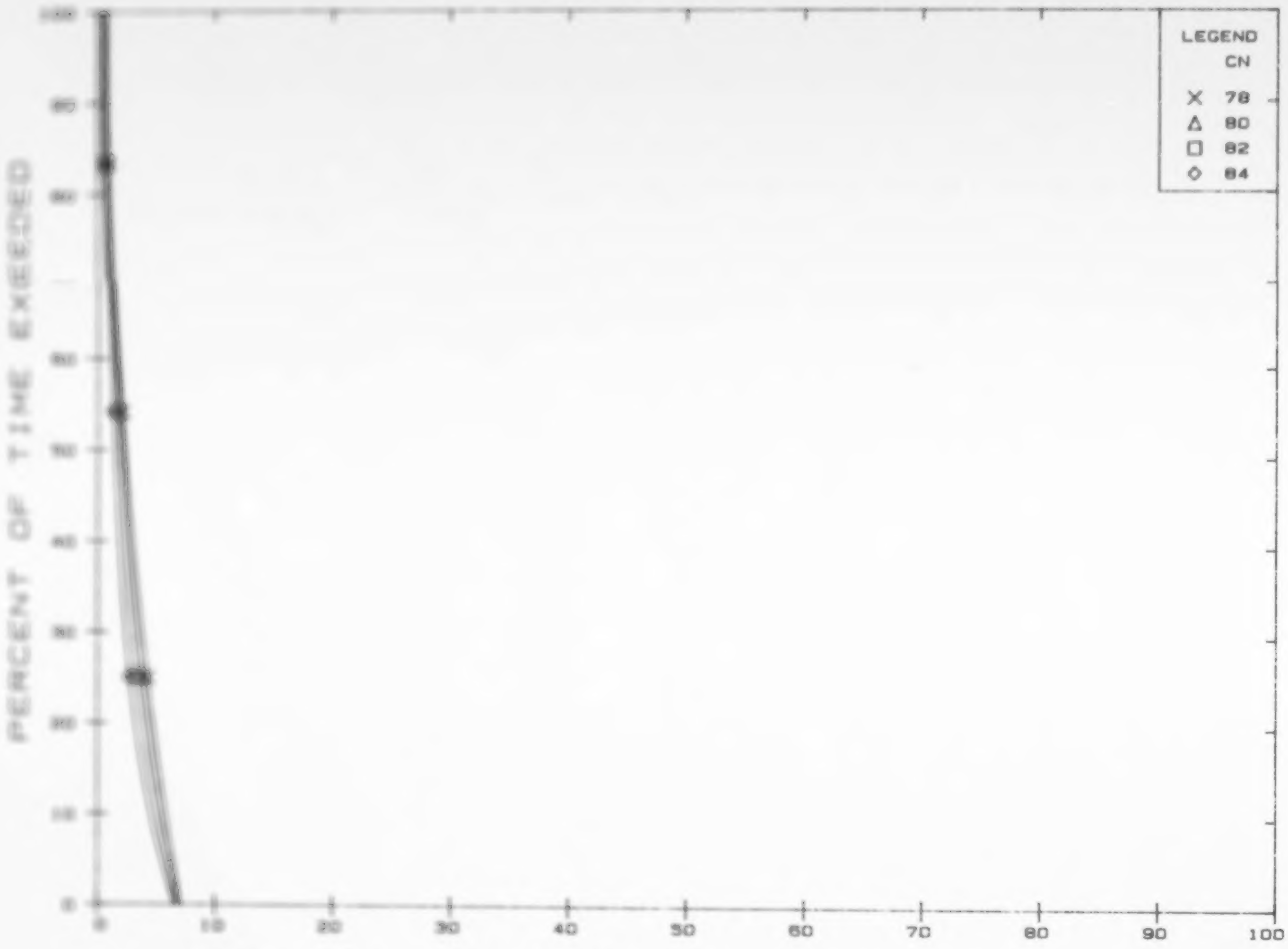
FIGURE A12-11 R=5. KS=.005



% OF APPLIED PESTICIDE LEACHED PER YEAR
FIGURE A12-12 R=5. KS=.010

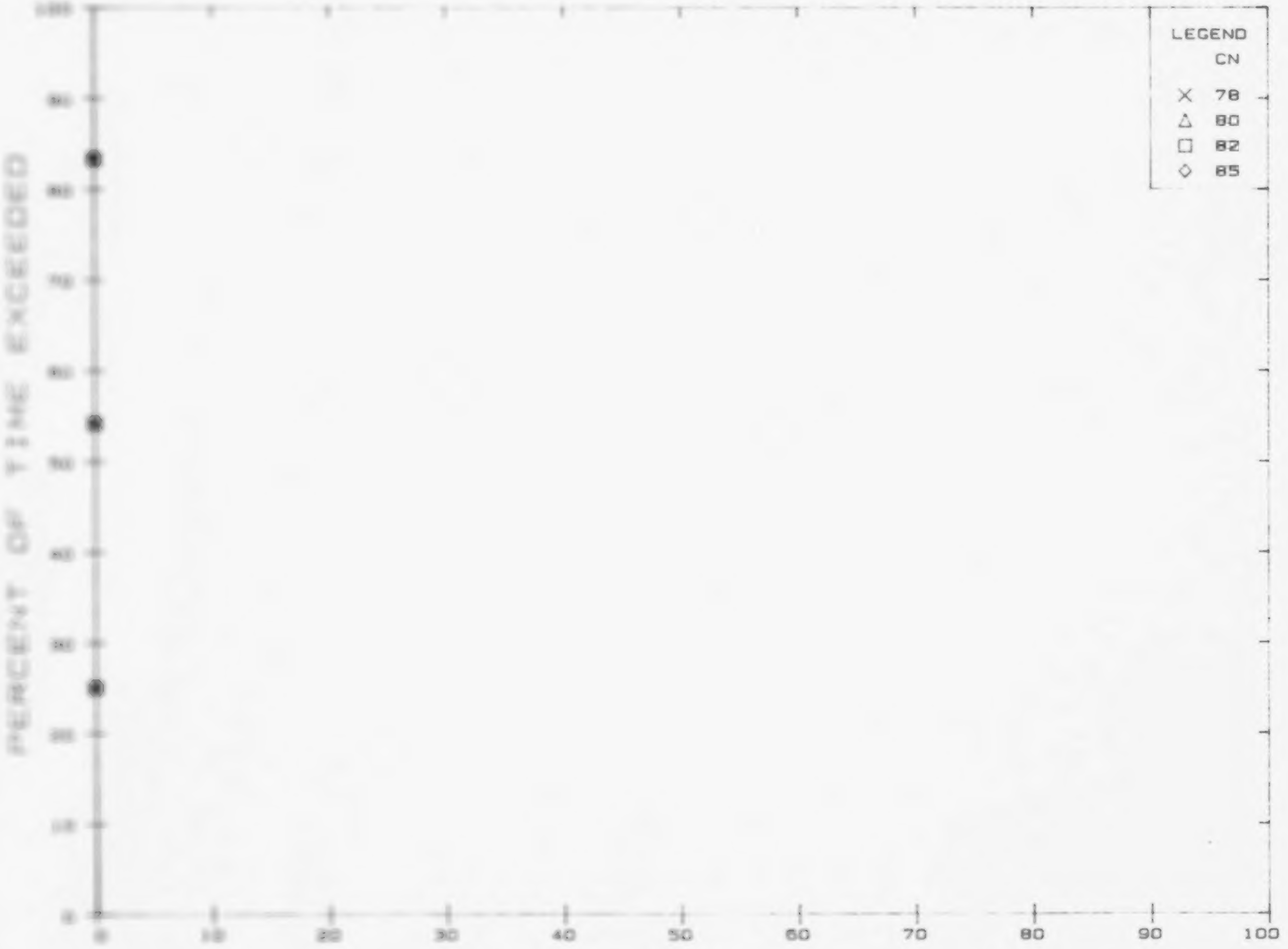


% OF APPLIED PESTICIDE LEACHED PER YEAR
FIGURE A12-13 R=5. KS=.050

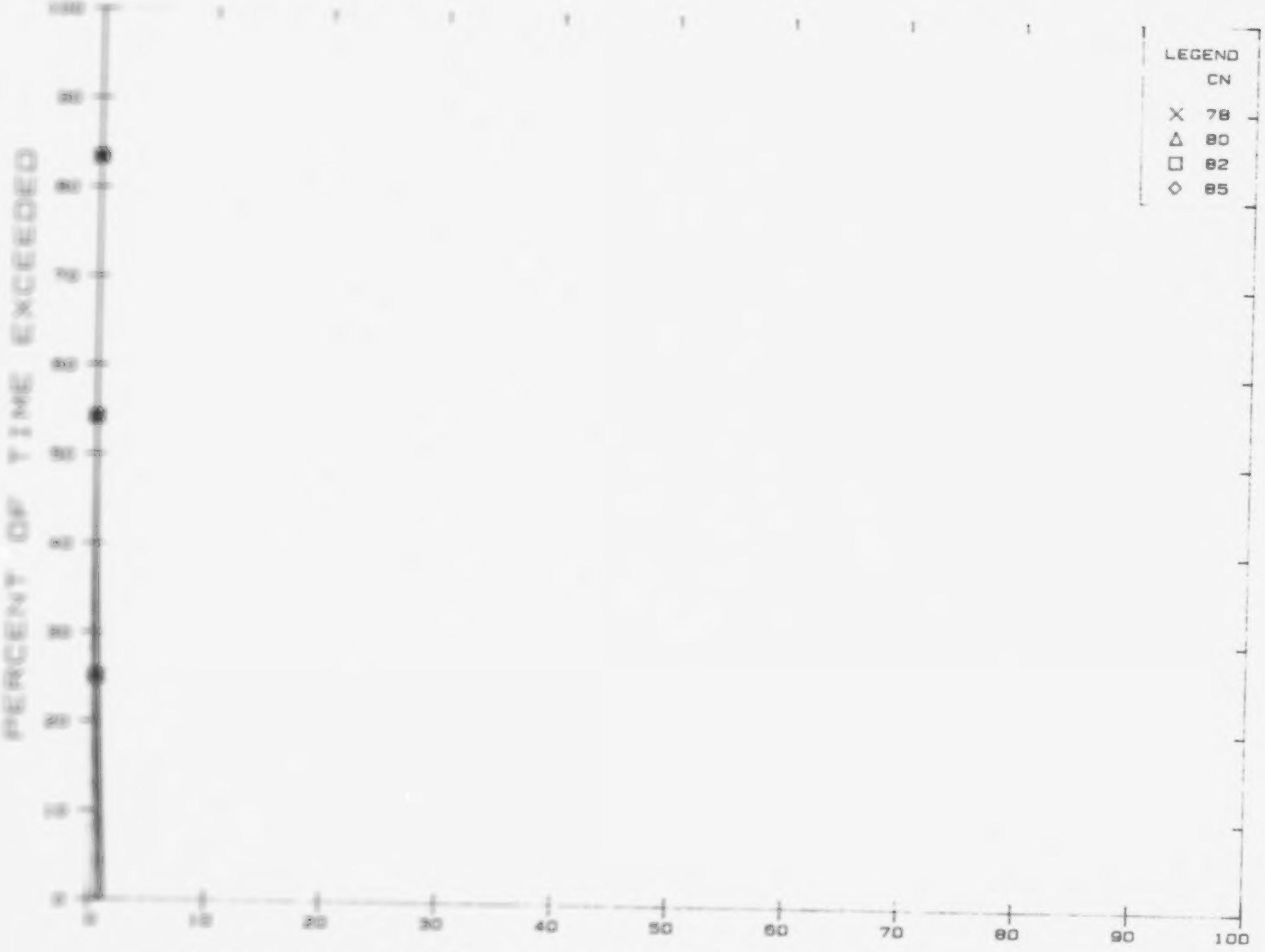


% OF APPLIED PESTICIDE LEACHED PER YEAR

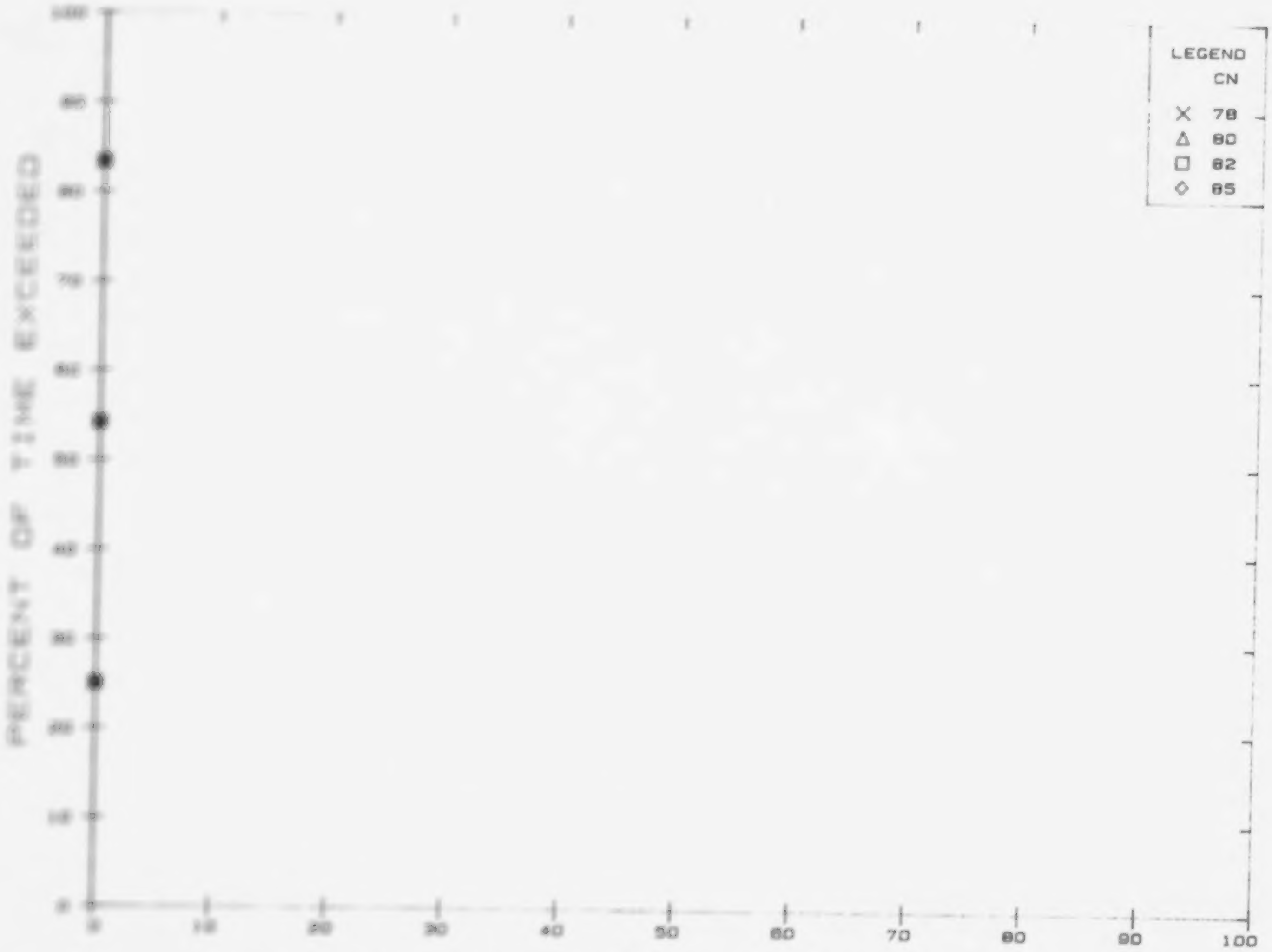
FIGURE A12-14 R=20. KS=.001



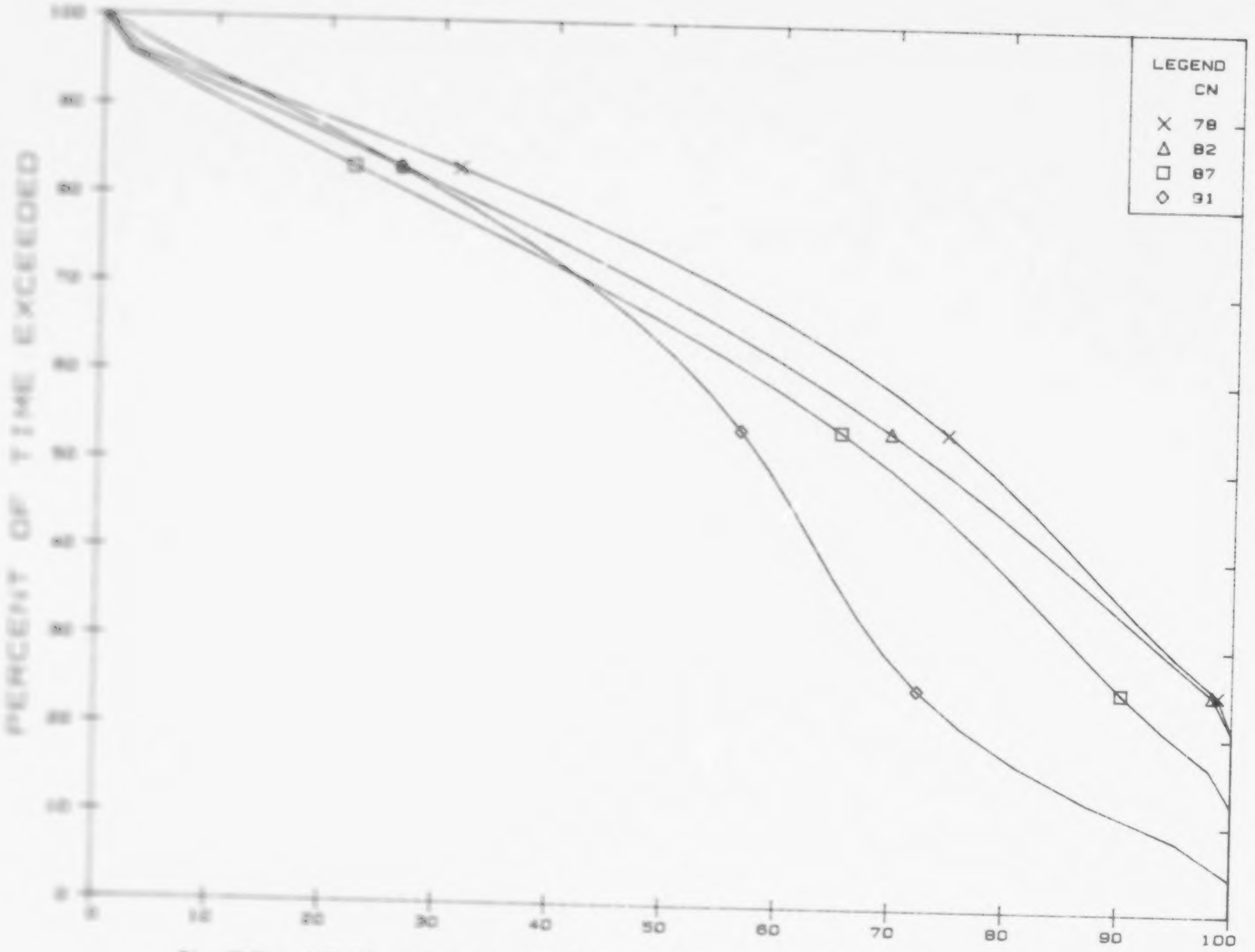
% OF APPLIED PESTICIDE LEACHED PER YEAR
FIGURE A12-15 R=20. KS=.005



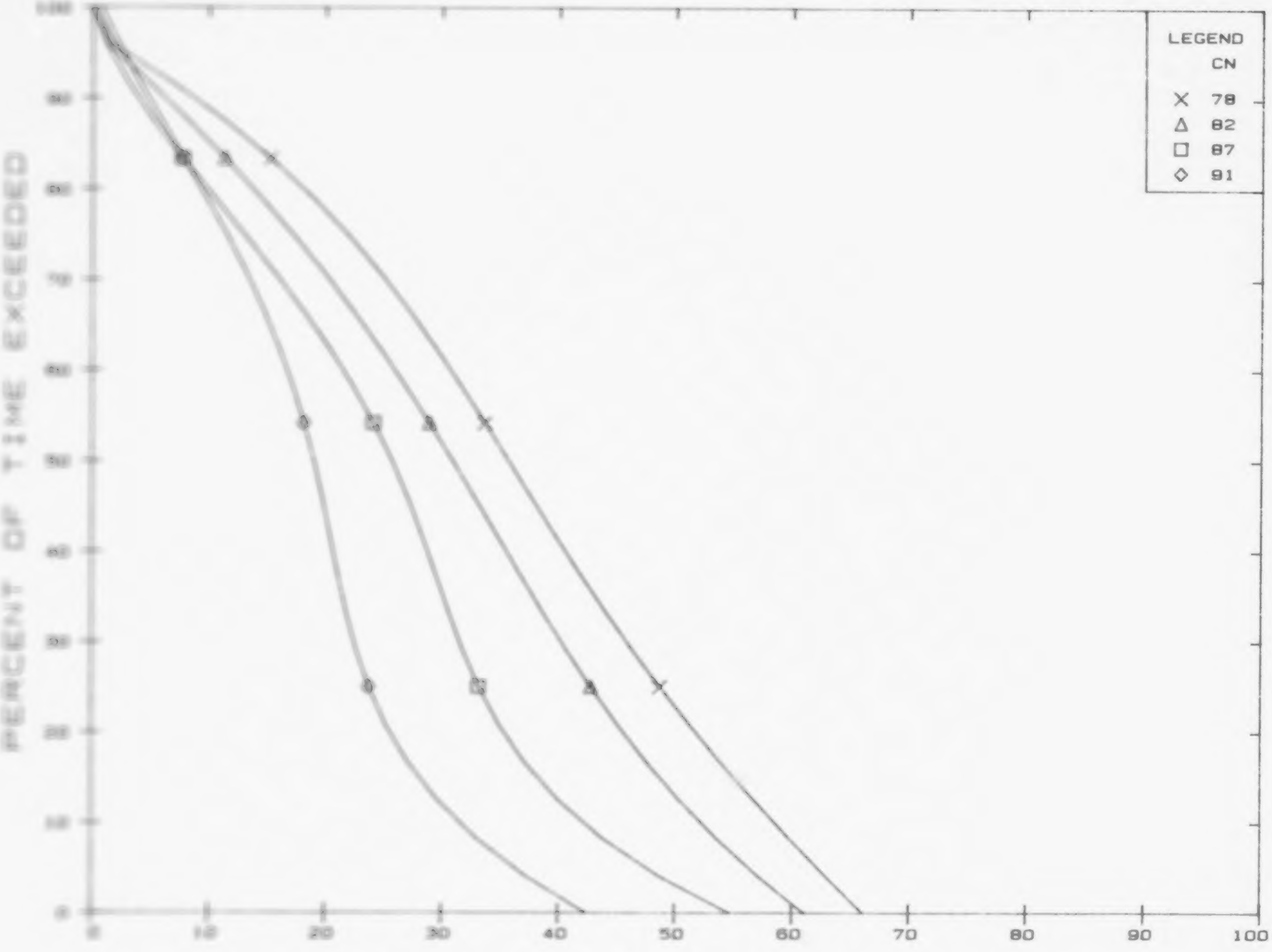
% OF APPLIED PESTICIDE LEACHED PER YEAR
FIGURE A12-16 R=50. KS=.001



% OF APPLIED PESTICIDE LEACHED PER YEAR
FIGURE A12-17 R=50. KS=.005

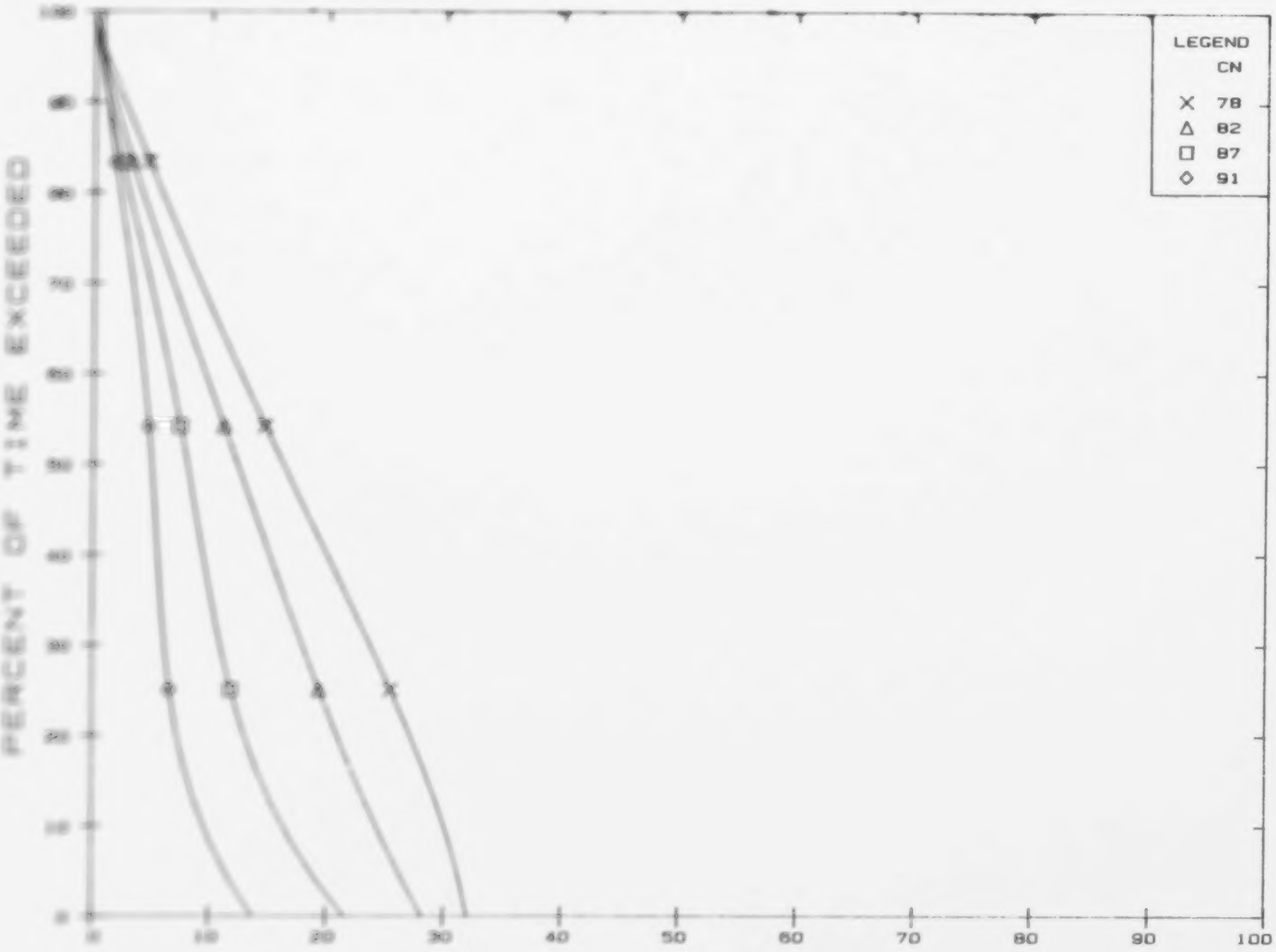


% OF APPLIED PESTICIDE LEACHED PER YEAR
FIGURE A13-1 R=1. KS=.001



% OF APPLIED PESTICIDE LEACHED PER YEAR

FIGURE A13-2 R=1. KS=.005



% OF APPLIED PESTICIDE LEACHED PER YEAR

FIGURE A13-3 R=1. KS=.010

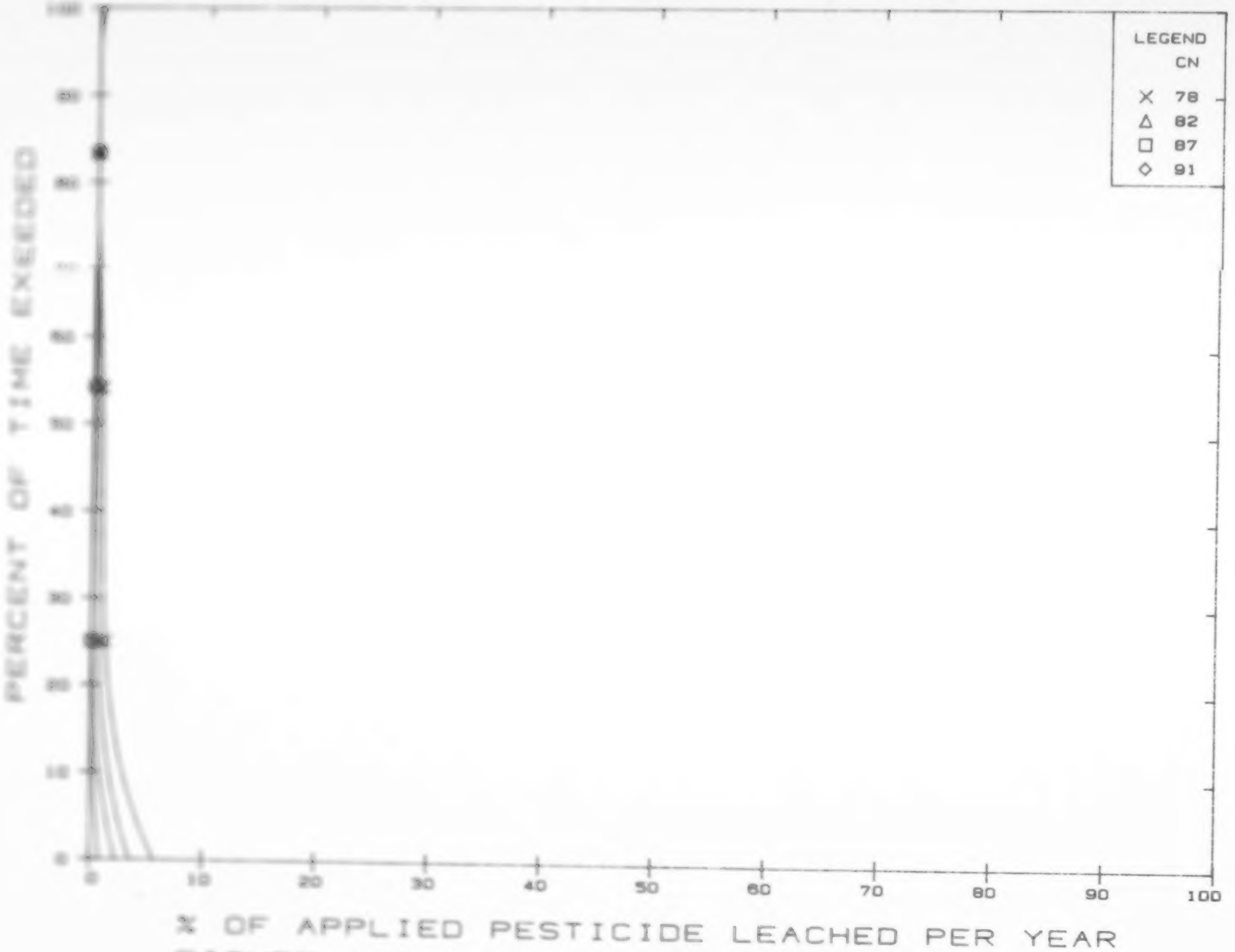


FIGURE A13-4 R=1. KS=.050

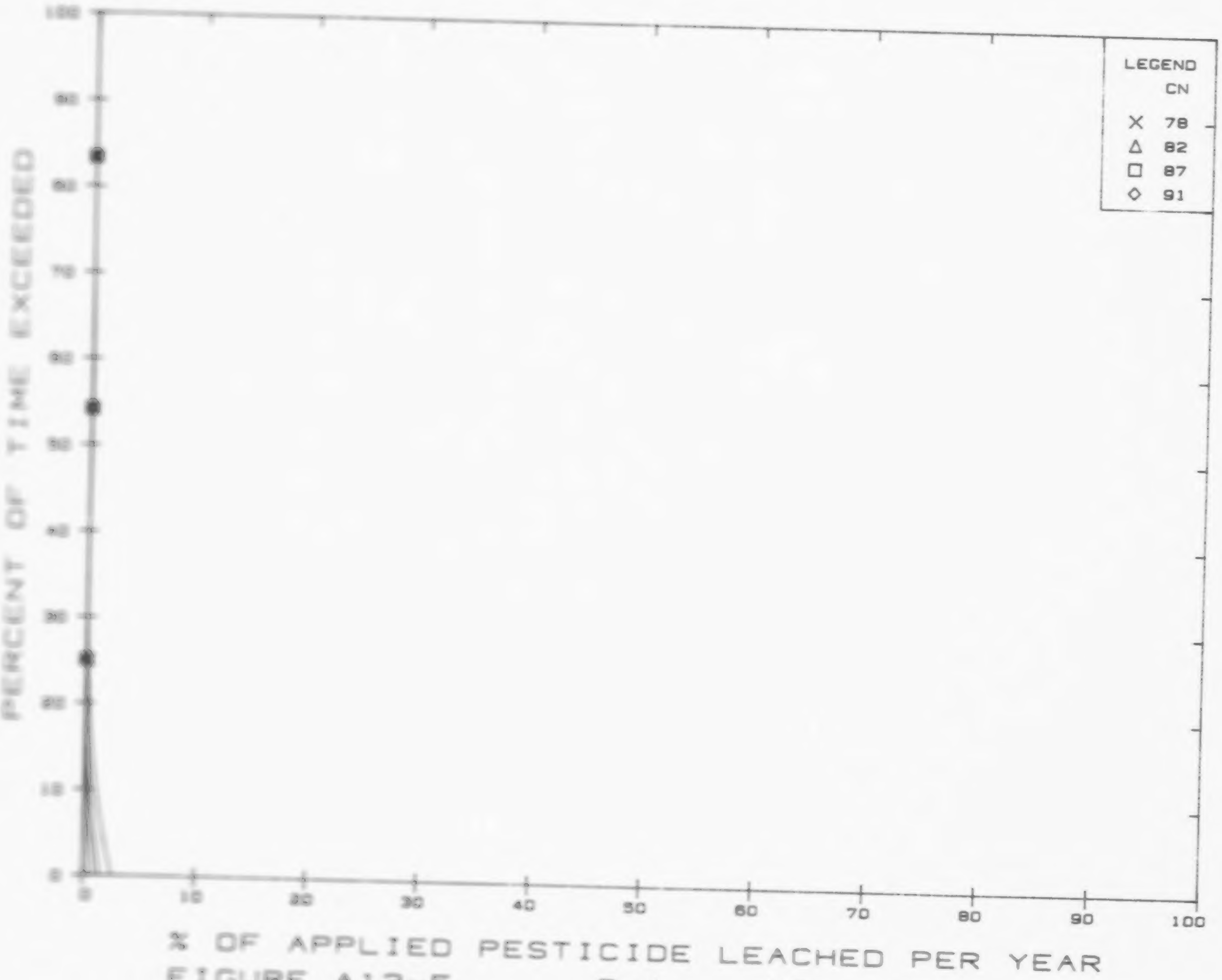


FIGURE A13-5 R=1. KS=.100

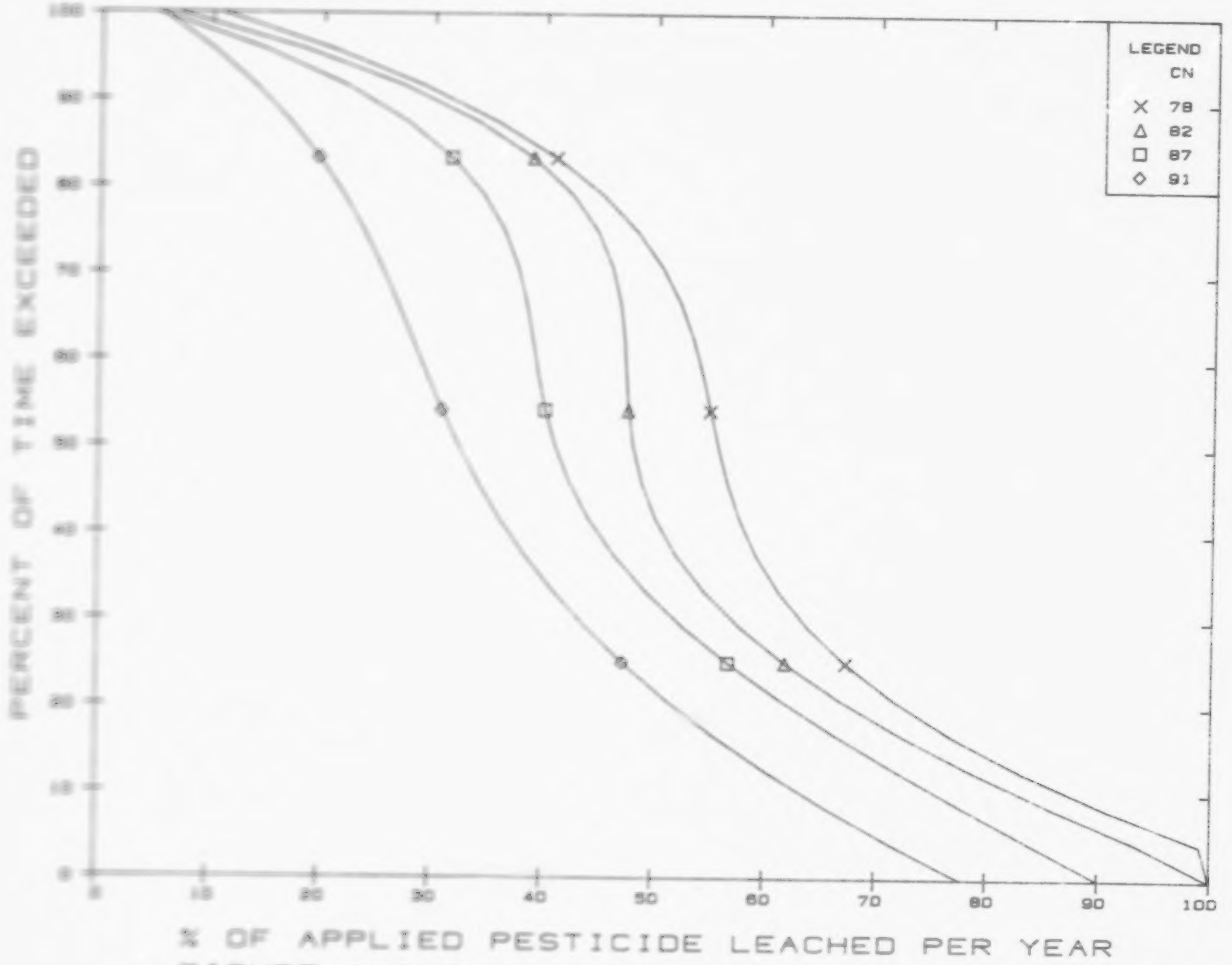
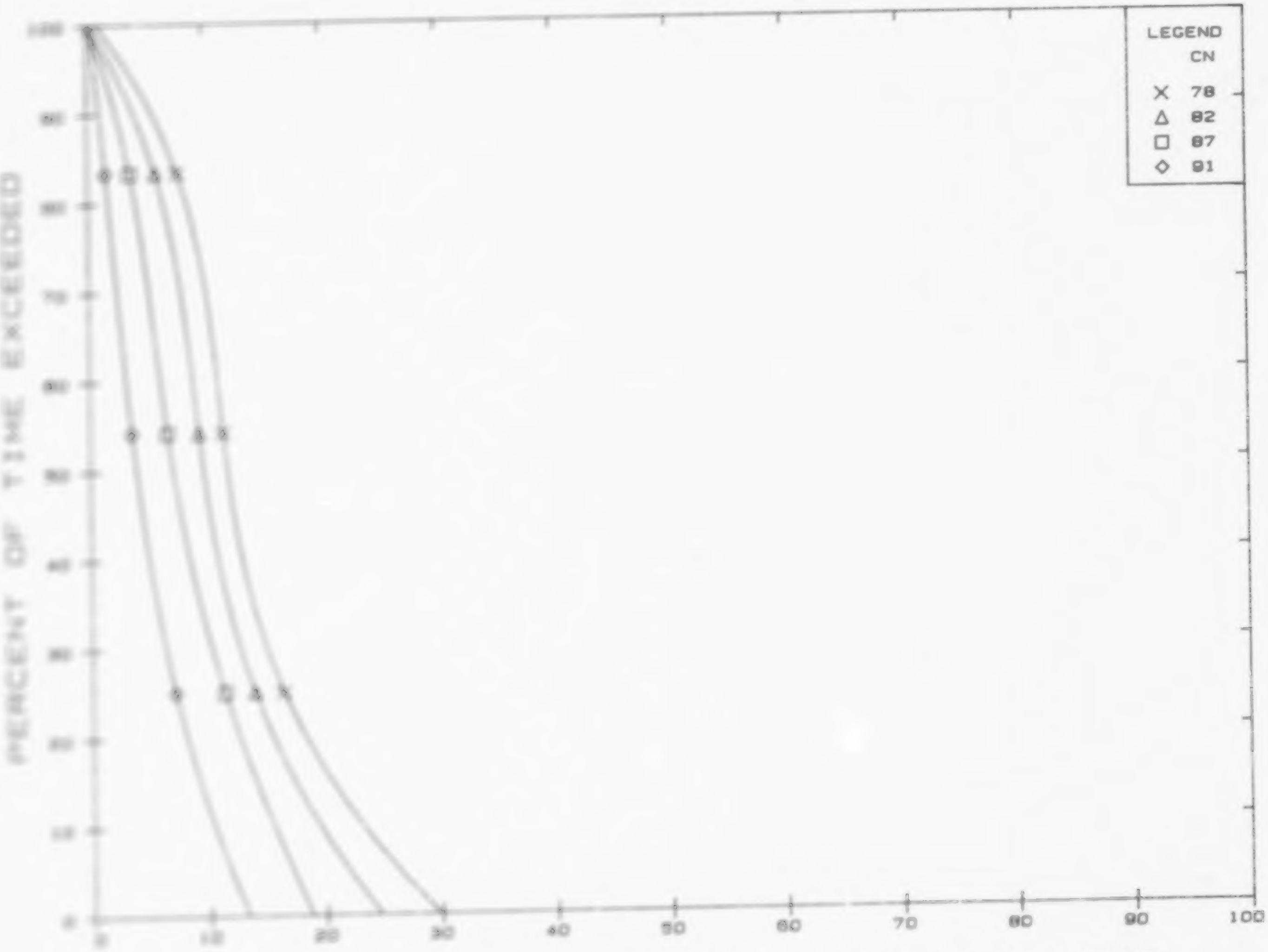


FIGURE A13-6 R=3. KS=.001



% OF APPLIED PESTICIDE LEACHED PER YEAR
FIGURE A13-7 R=3. KS=.005

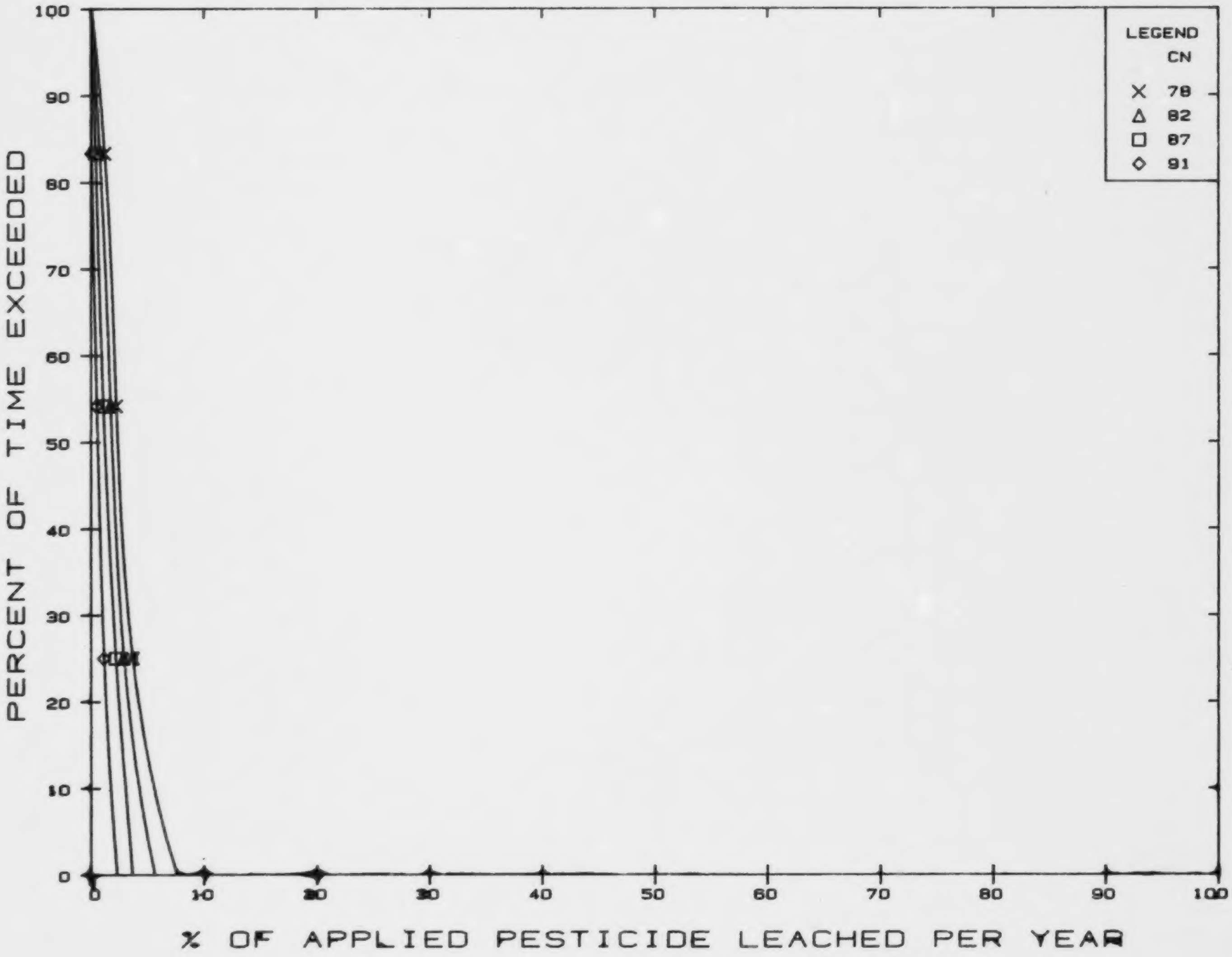


FIGURE A13-8 R=3. KS=.010

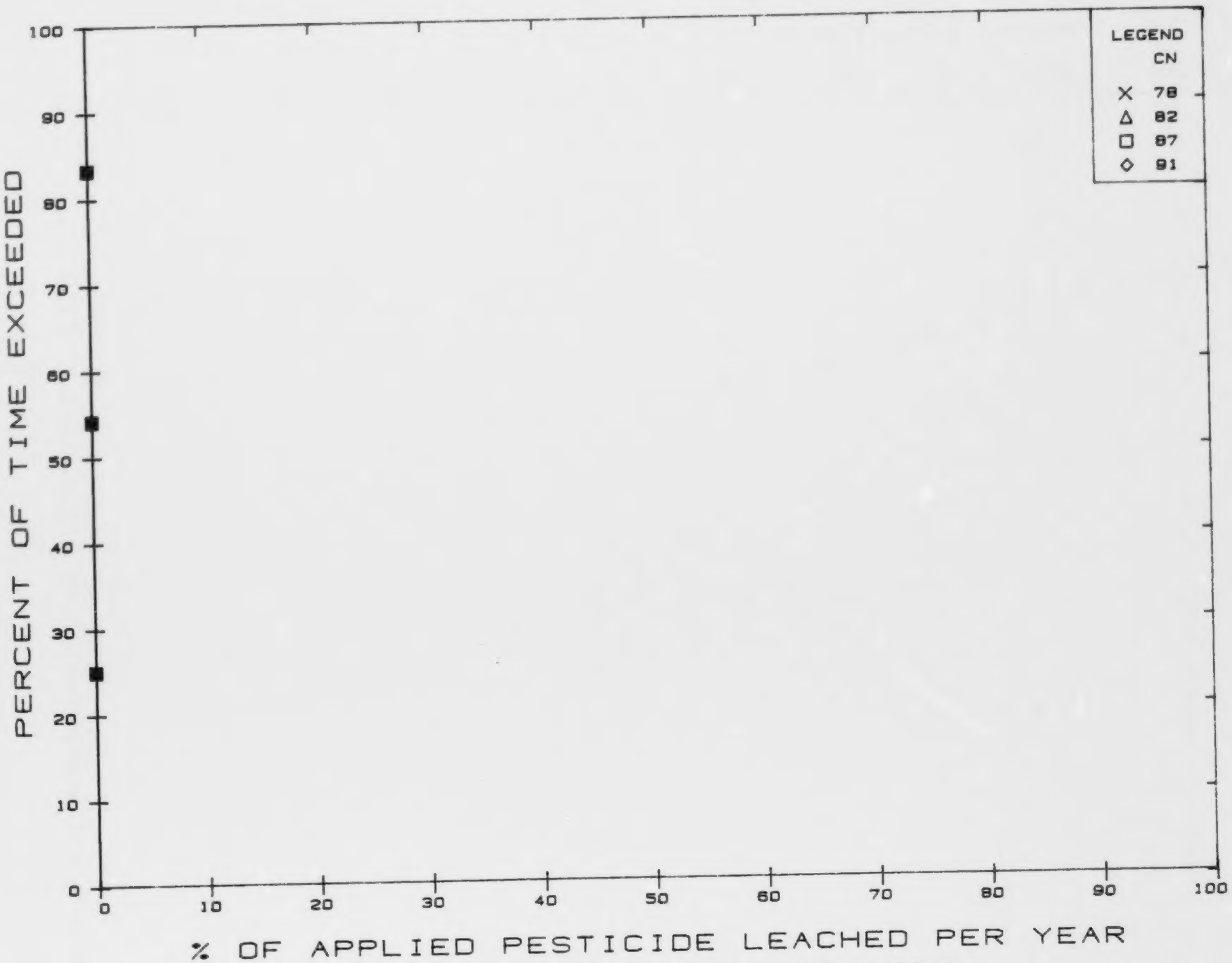


FIGURE A13-9 R=3. KS=.050

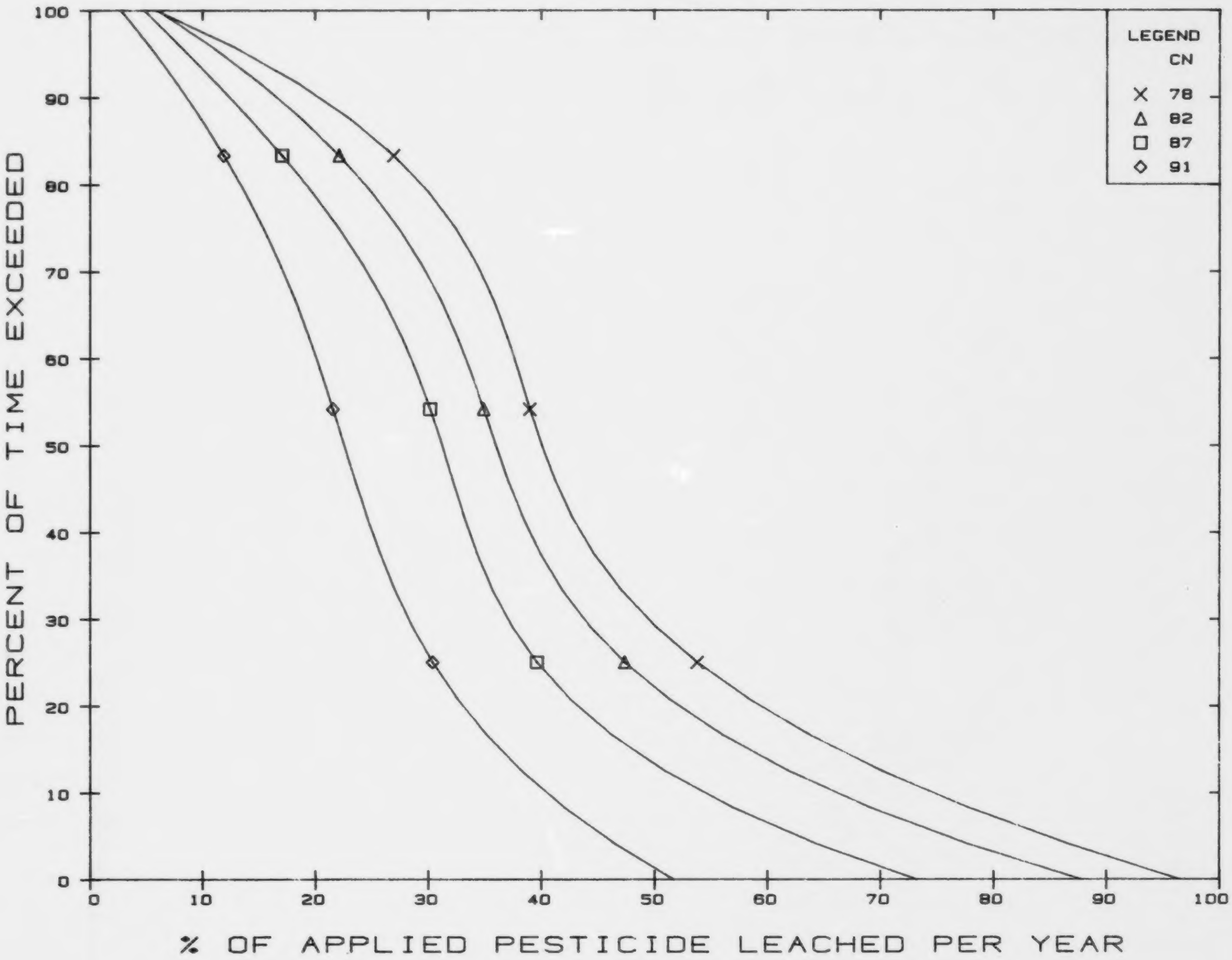


FIGURE A13-10 R=5. KS=.001

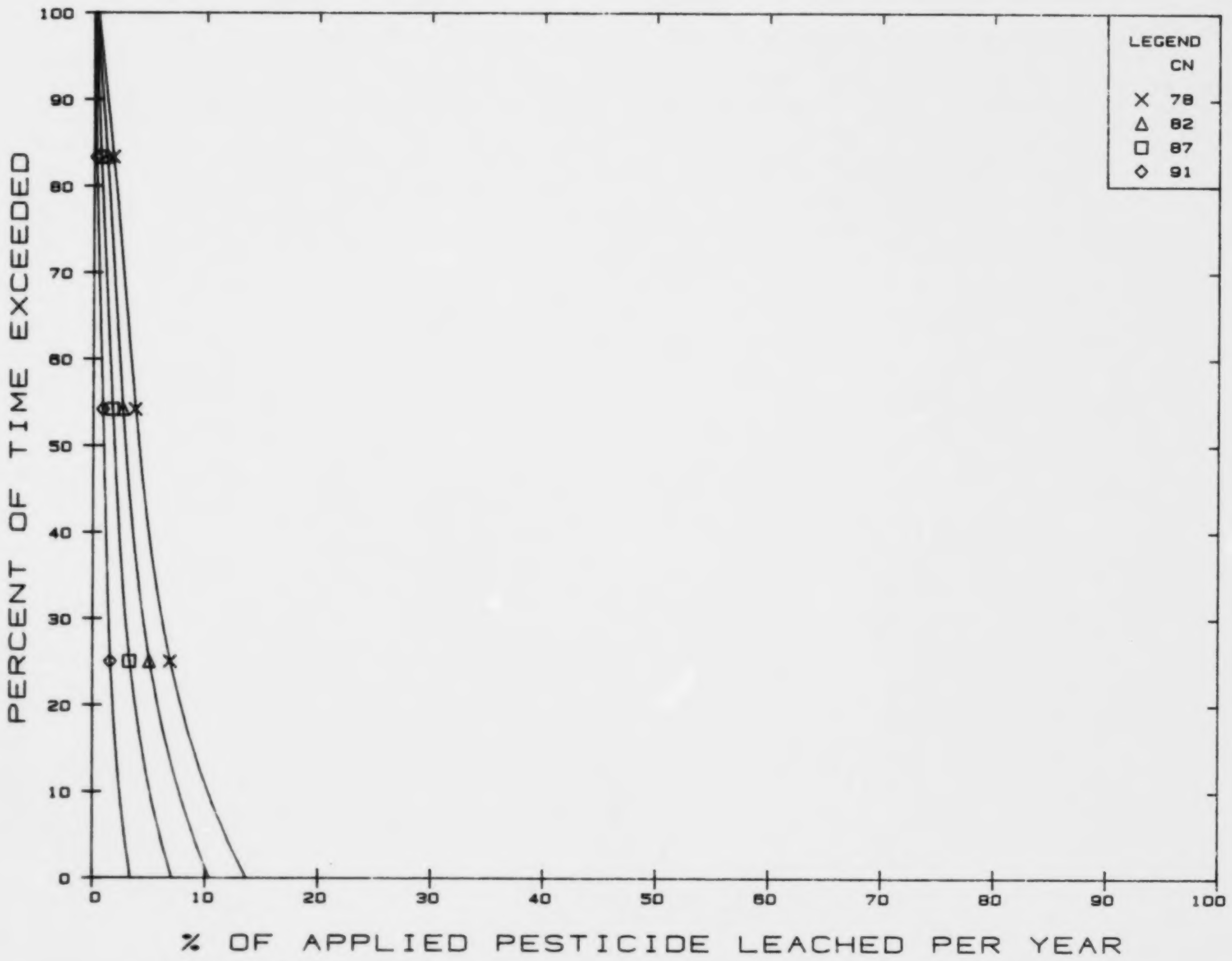


FIGURE A13-11 R=5. KS=.005

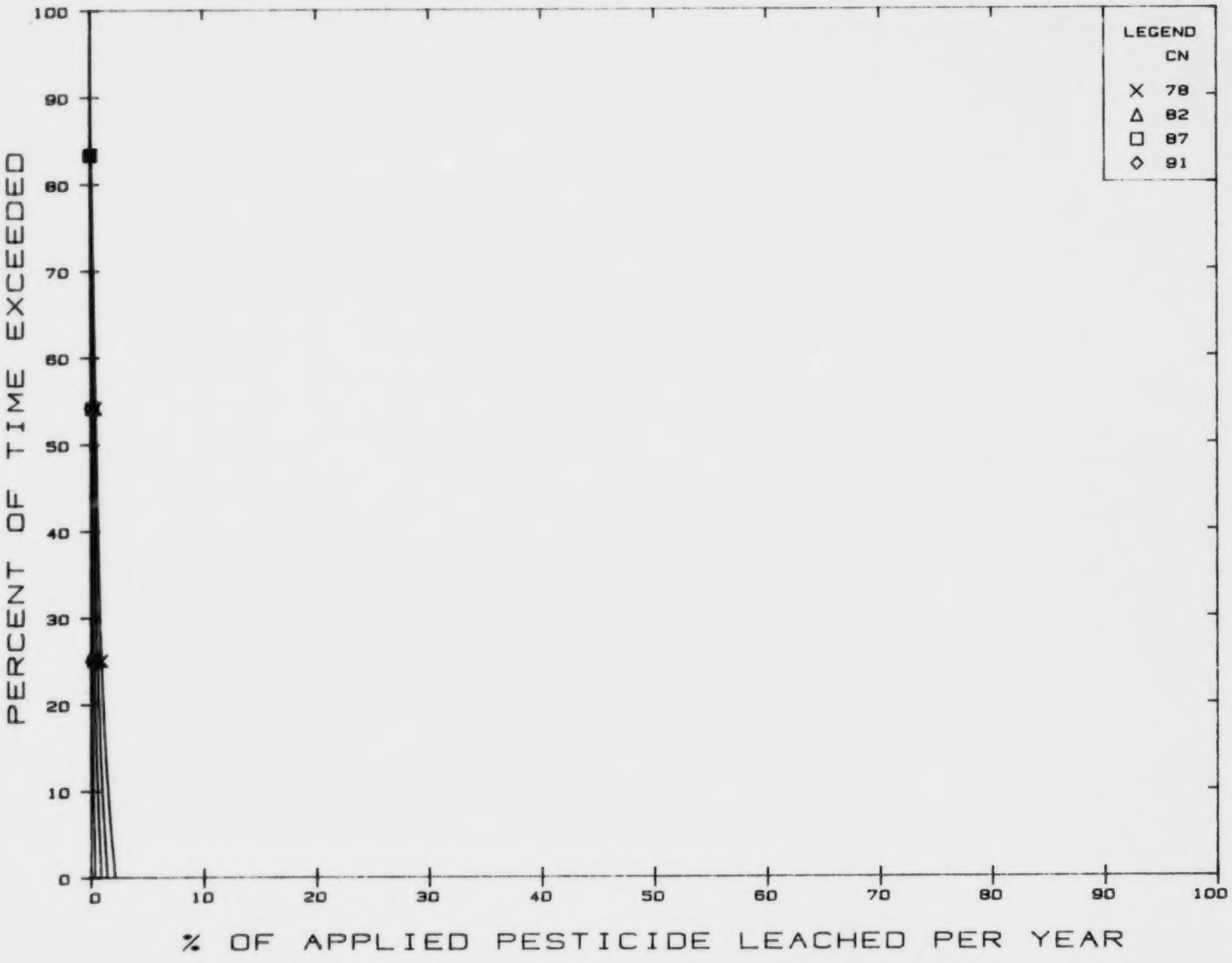


FIGURE A13-12 R=5. KS=.010

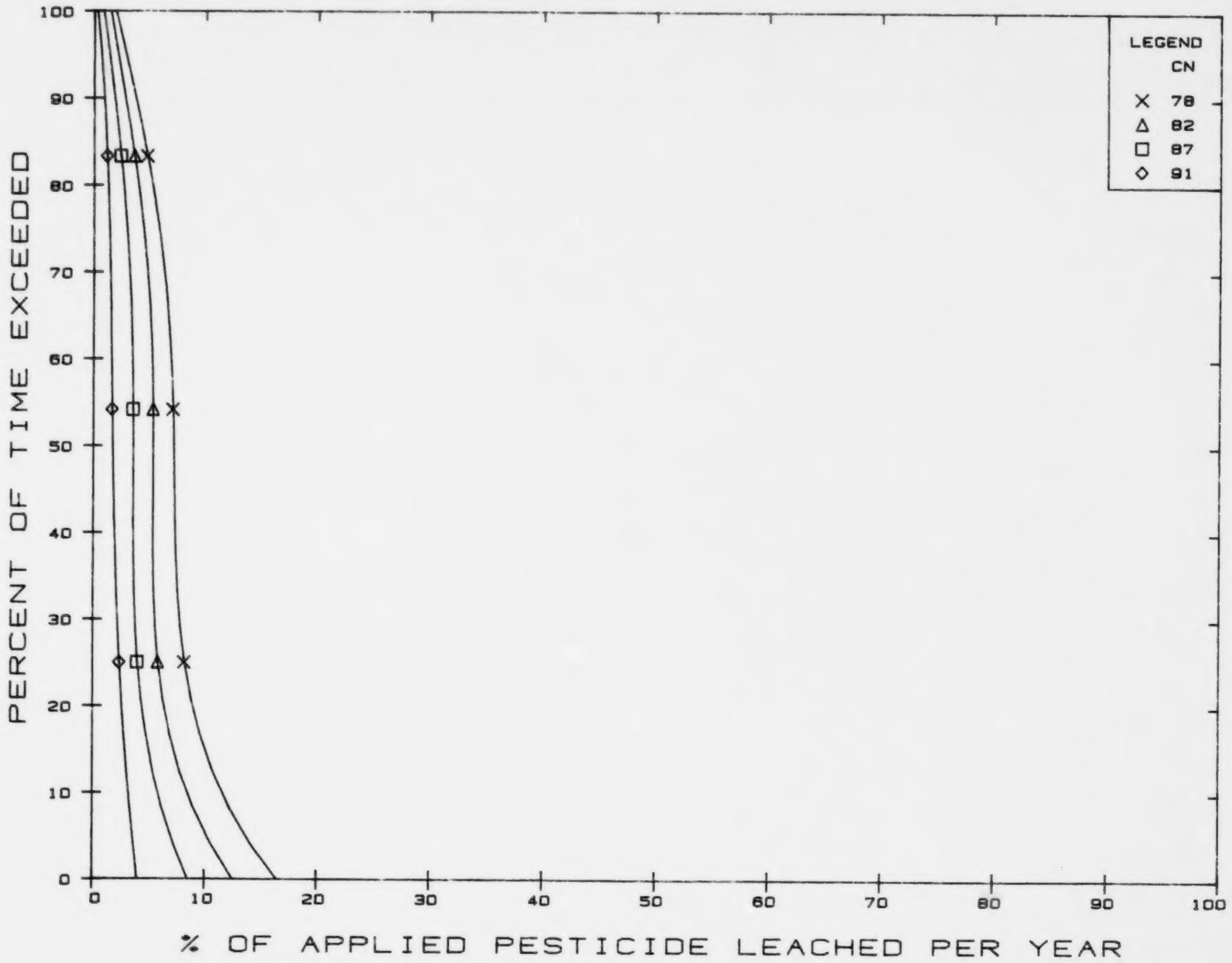


FIGURE A13-13 R=20. KS=.001

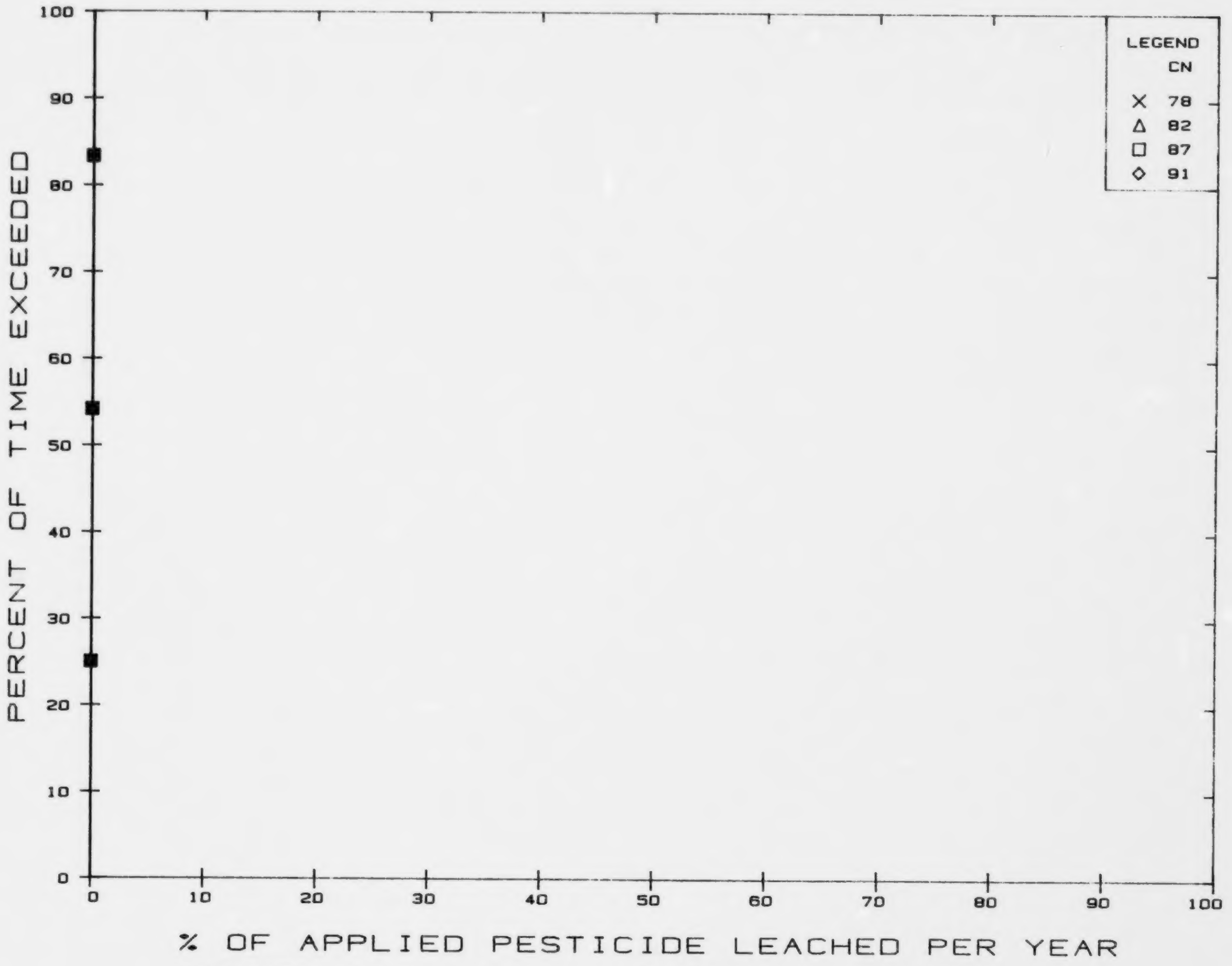


FIGURE A13-14 R=20. KS=.005

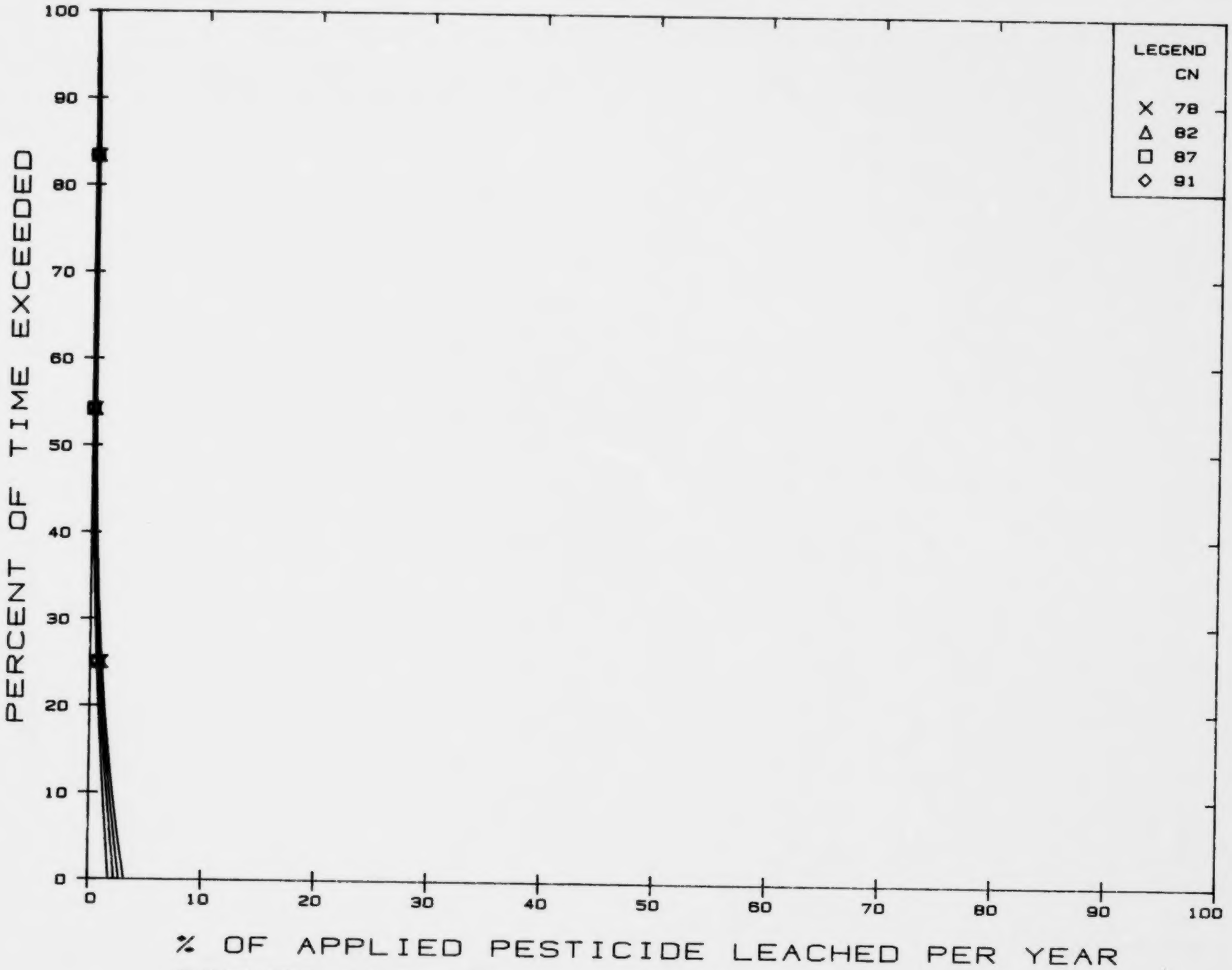


FIGURE A13-15 R=50. KS=.001

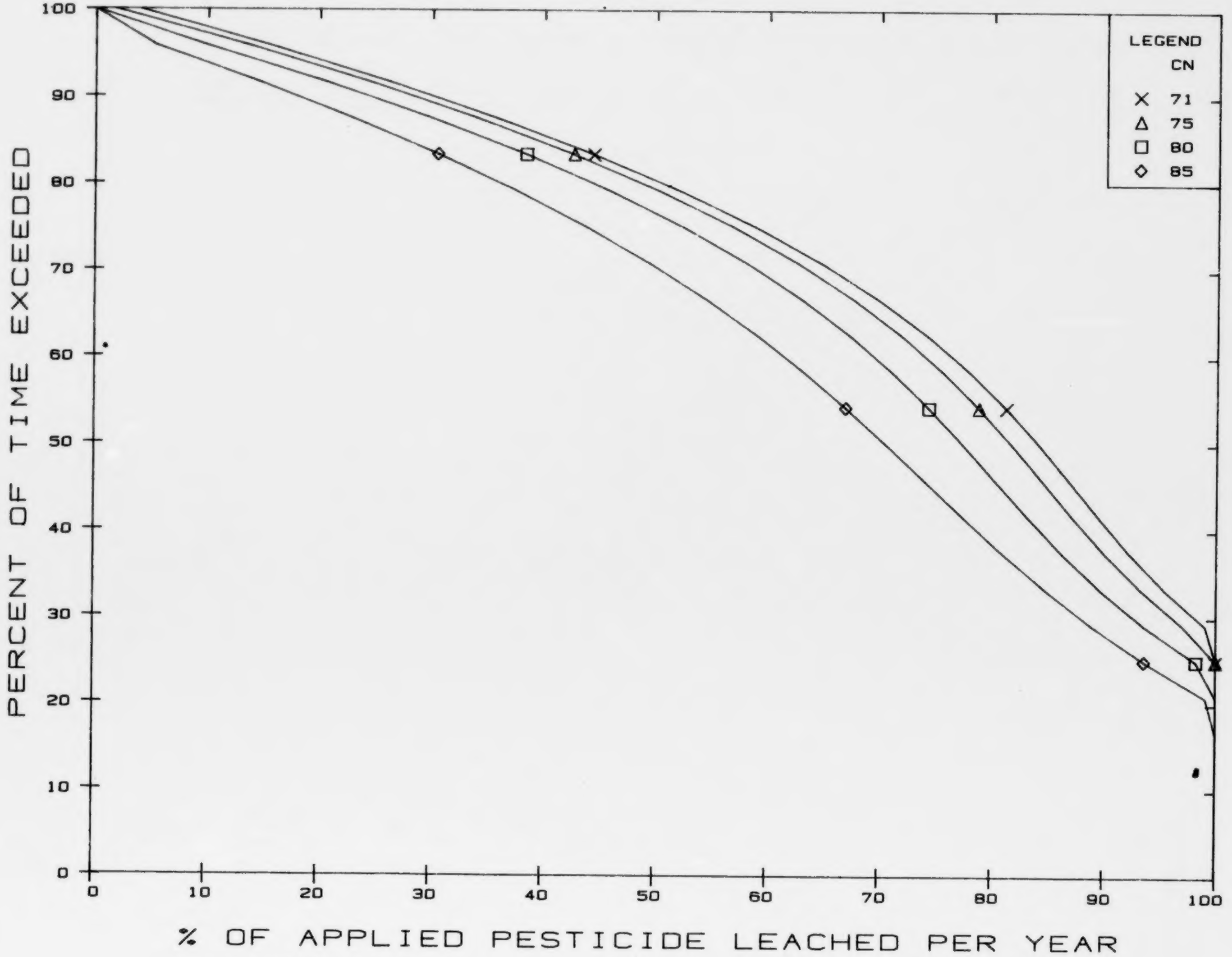


FIGURE A14-1 R=1. KS=.001

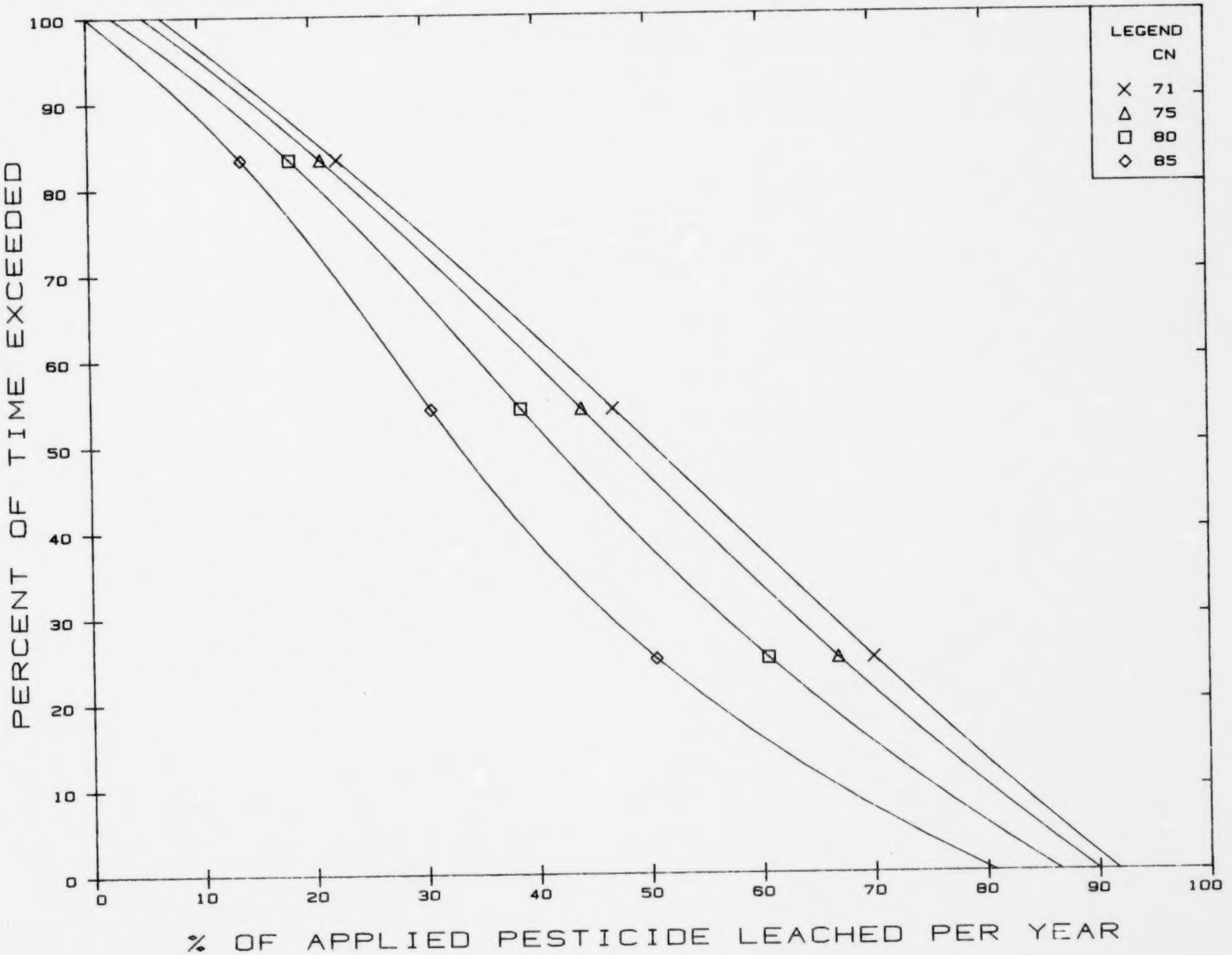


FIGURE A14-2 R=1. KS=.005

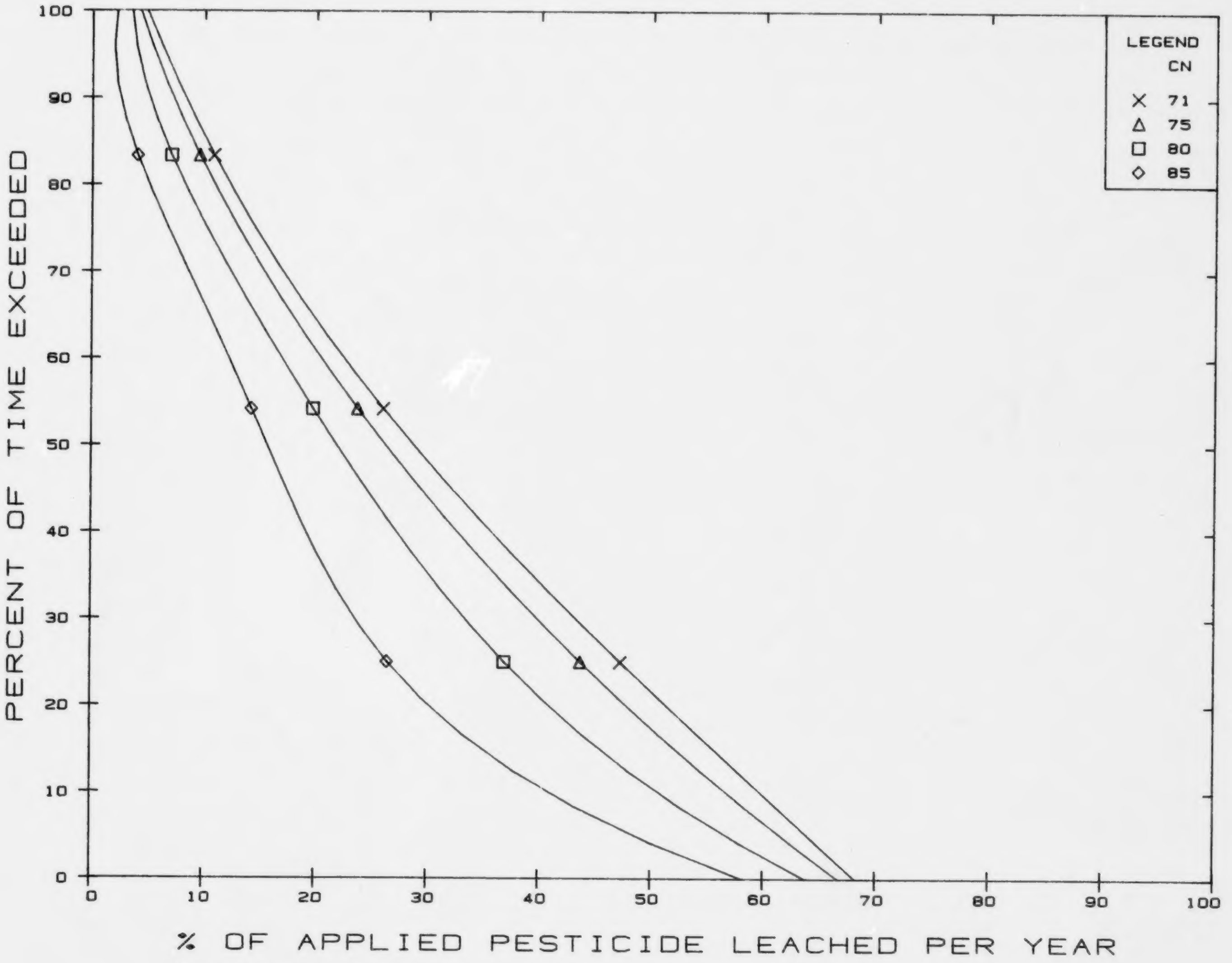


FIGURE A14-3 R=1. KS=.010

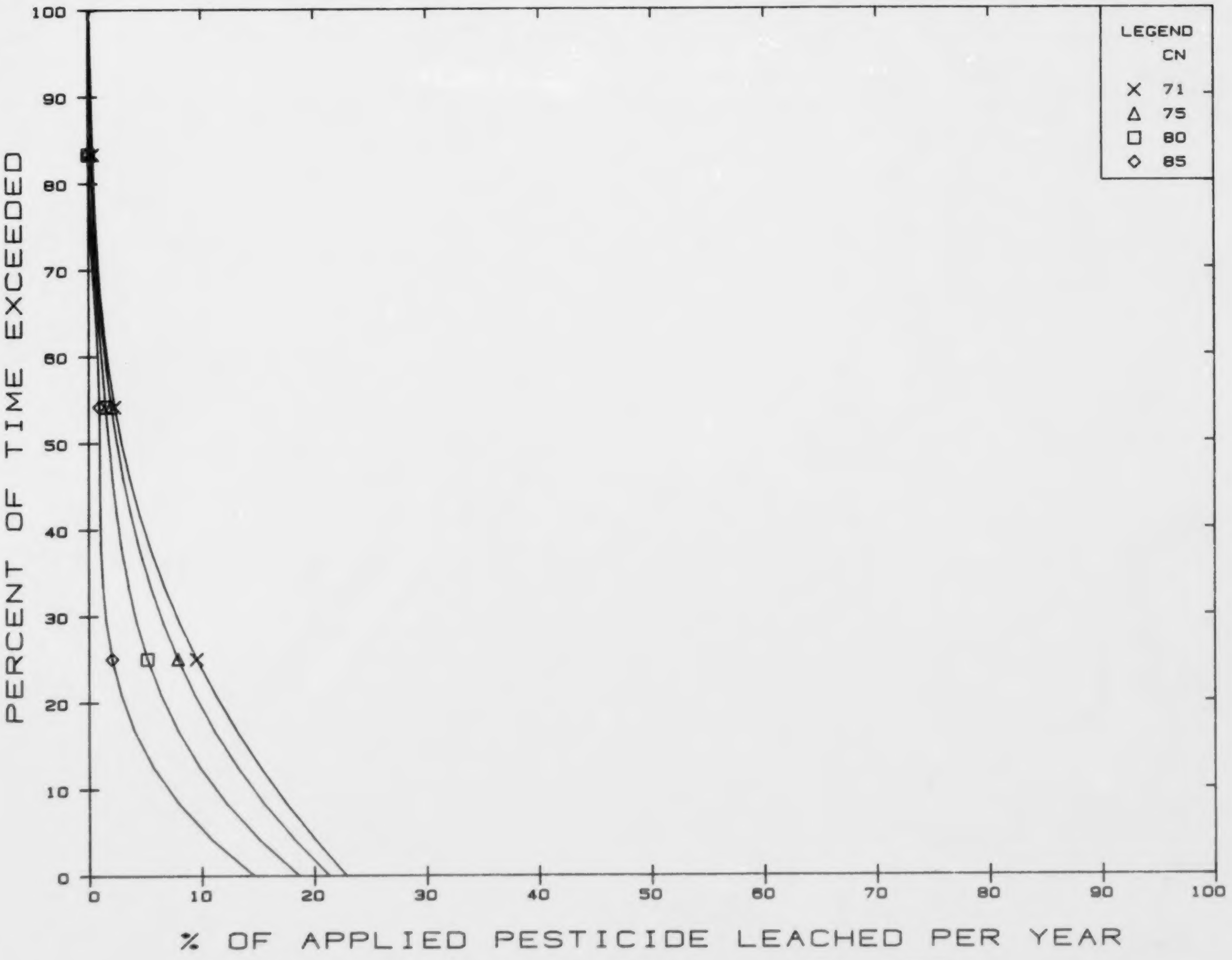


FIGURE A14-4 R=1. KS=.050

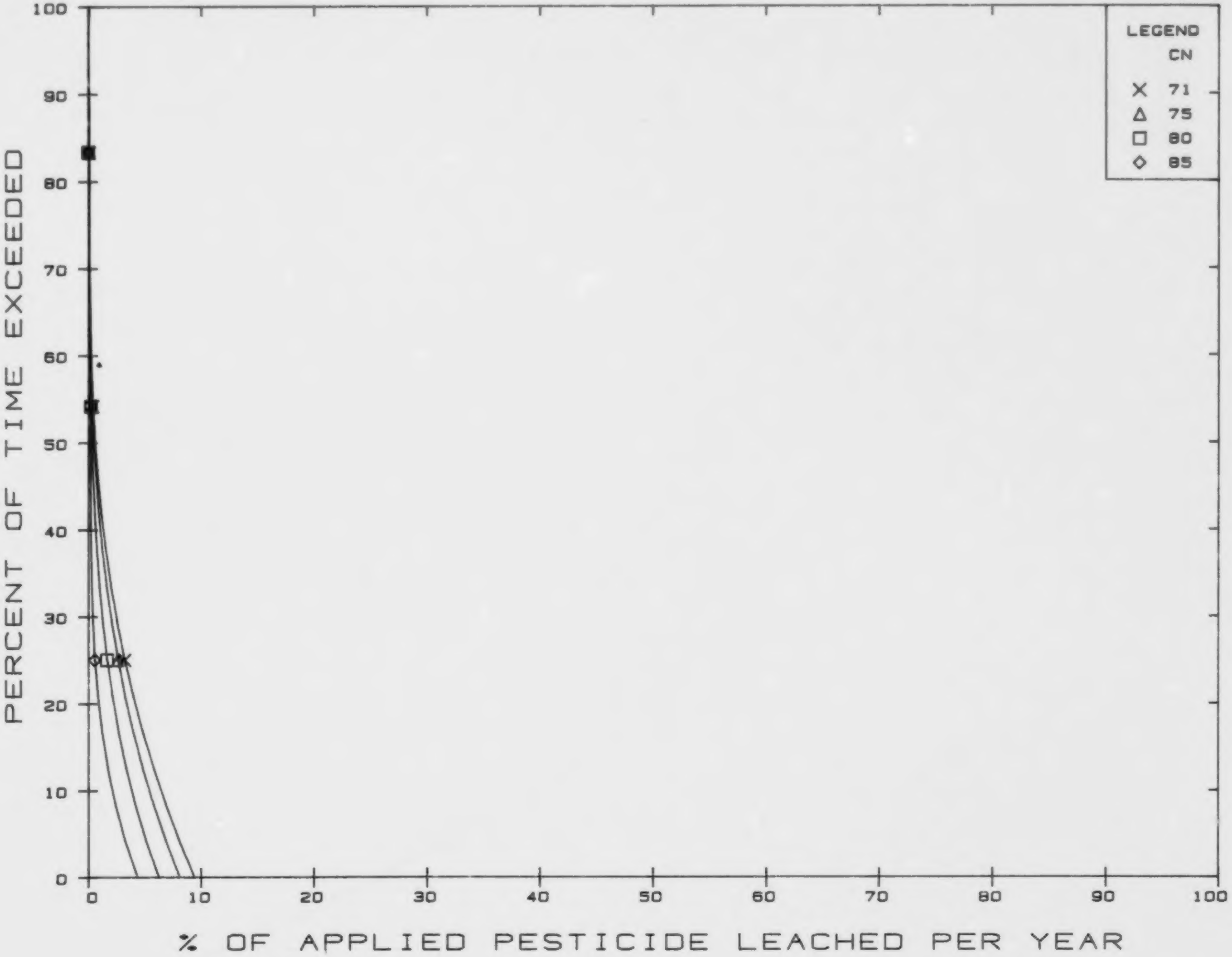


FIGURE A14-5 R=1. KS=.100

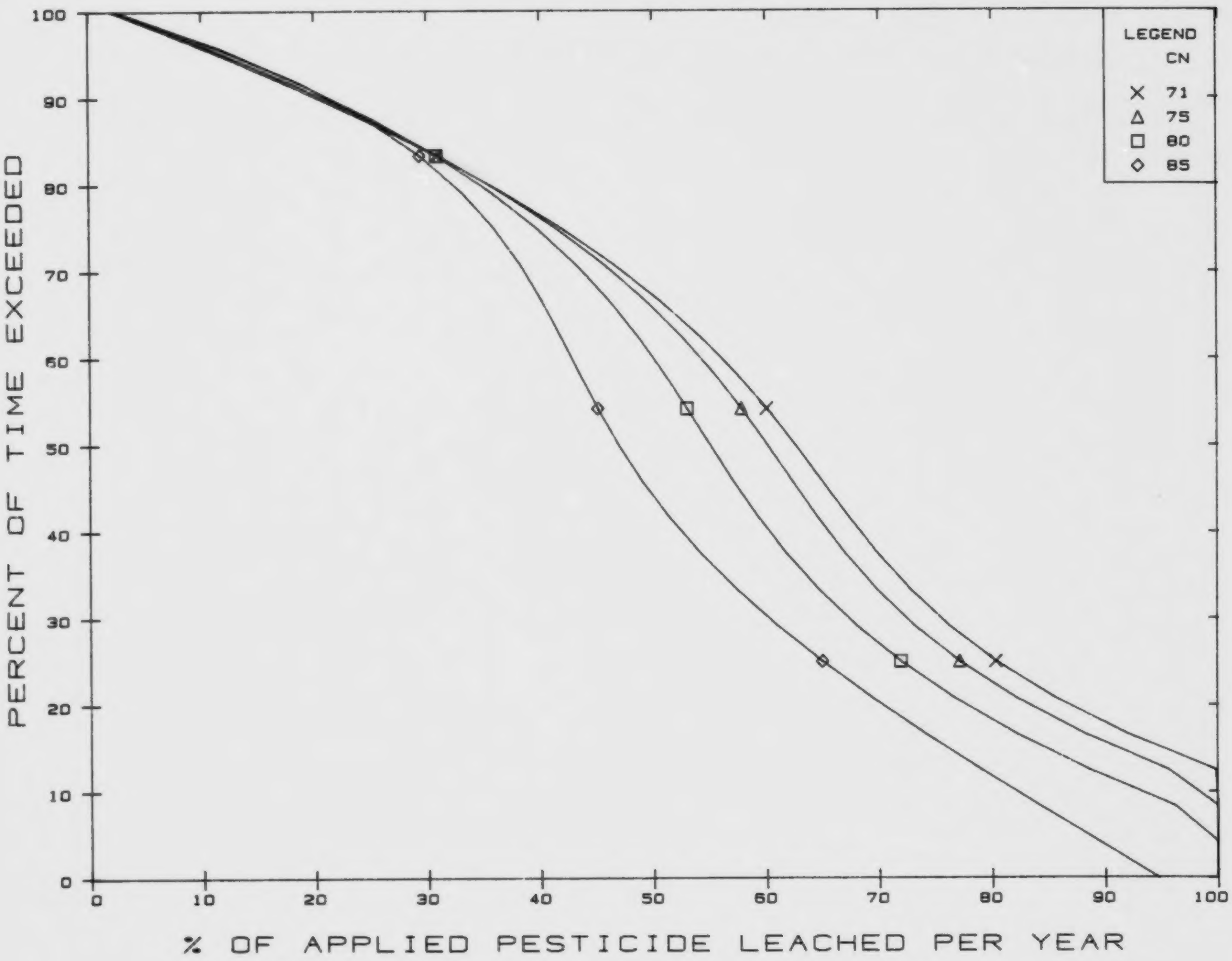


FIGURE A14-6 R=3. KS=.001

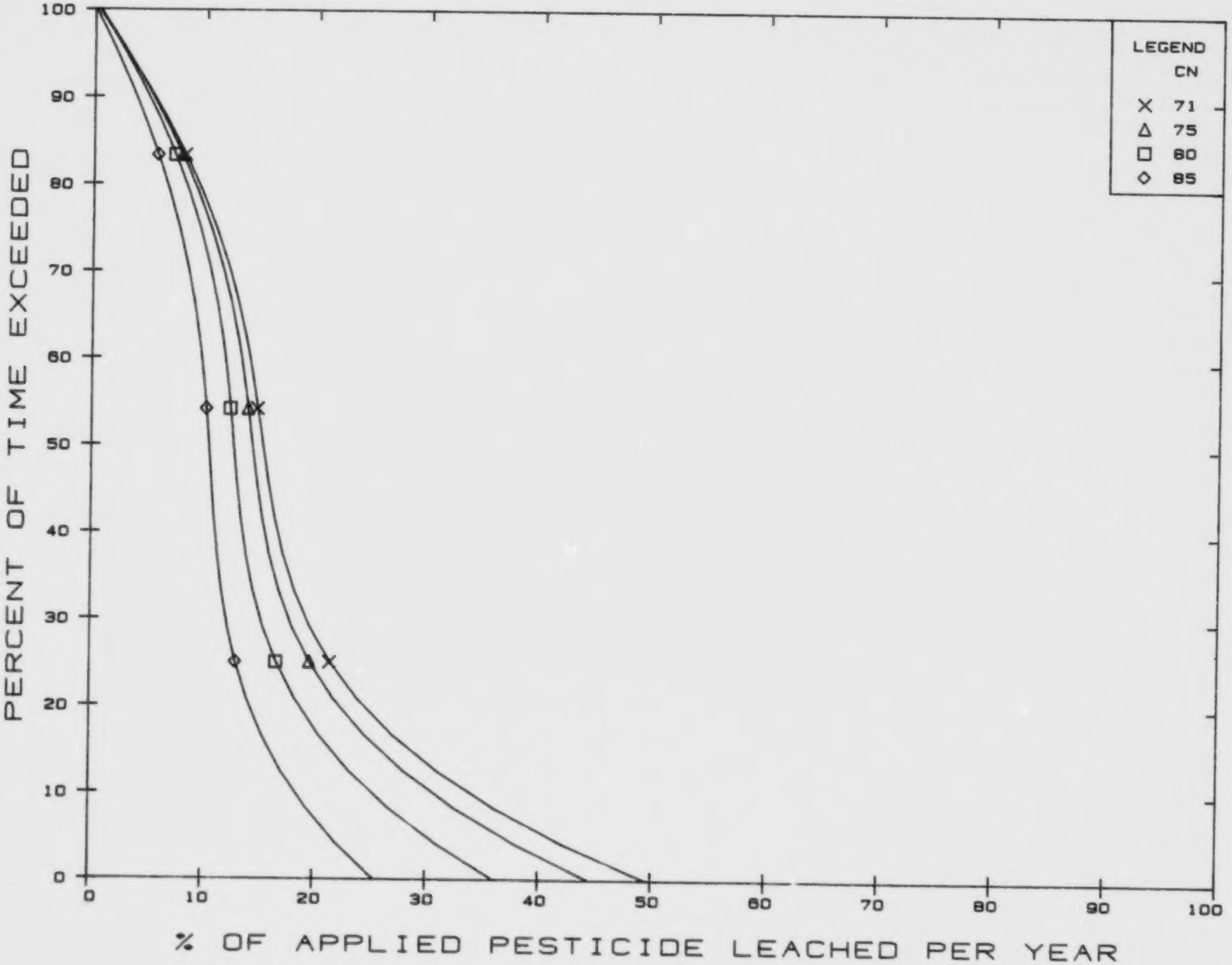


FIGURE A14-7 R=3. KS=.005

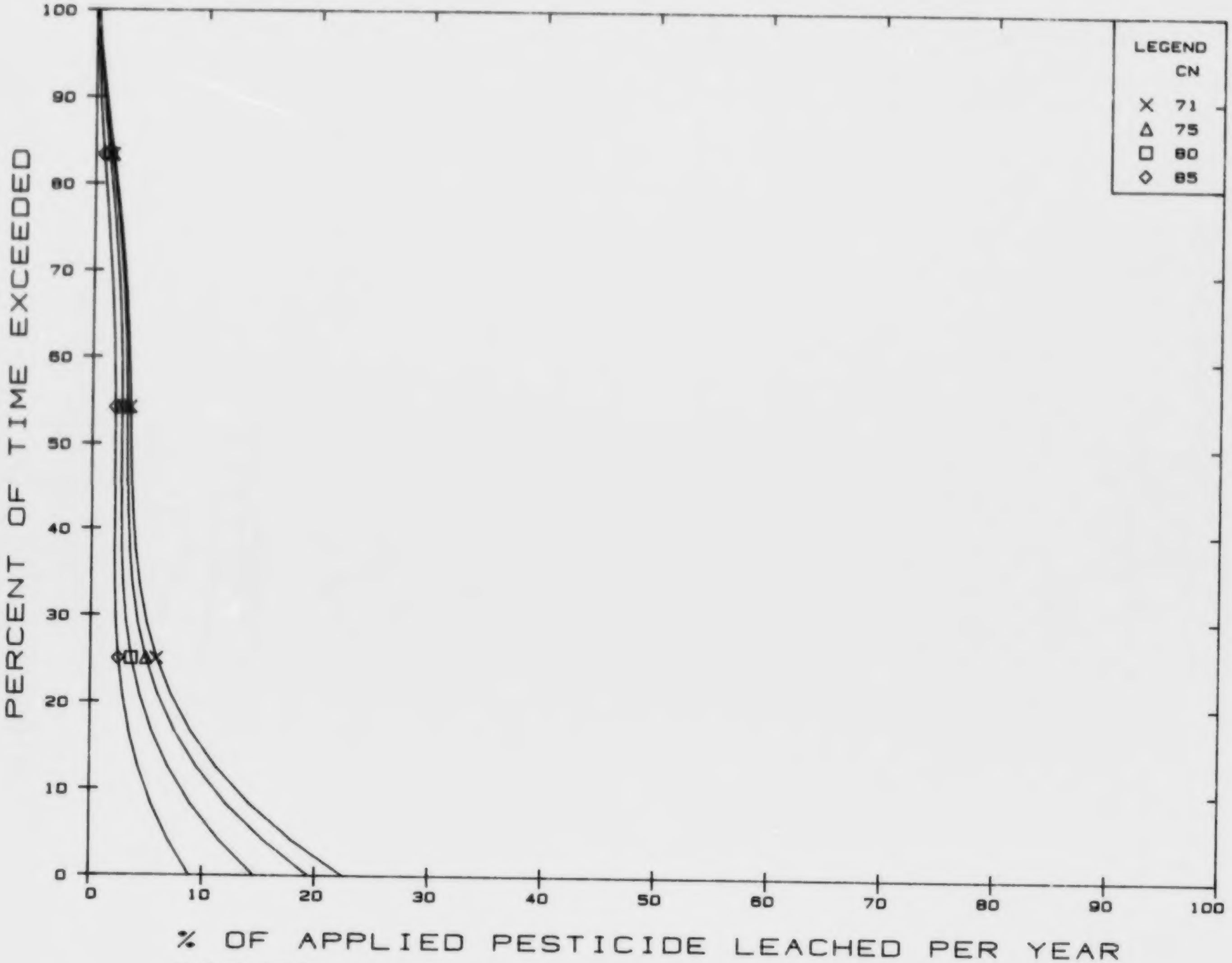


FIGURE A14-8 R=3. KS=.010

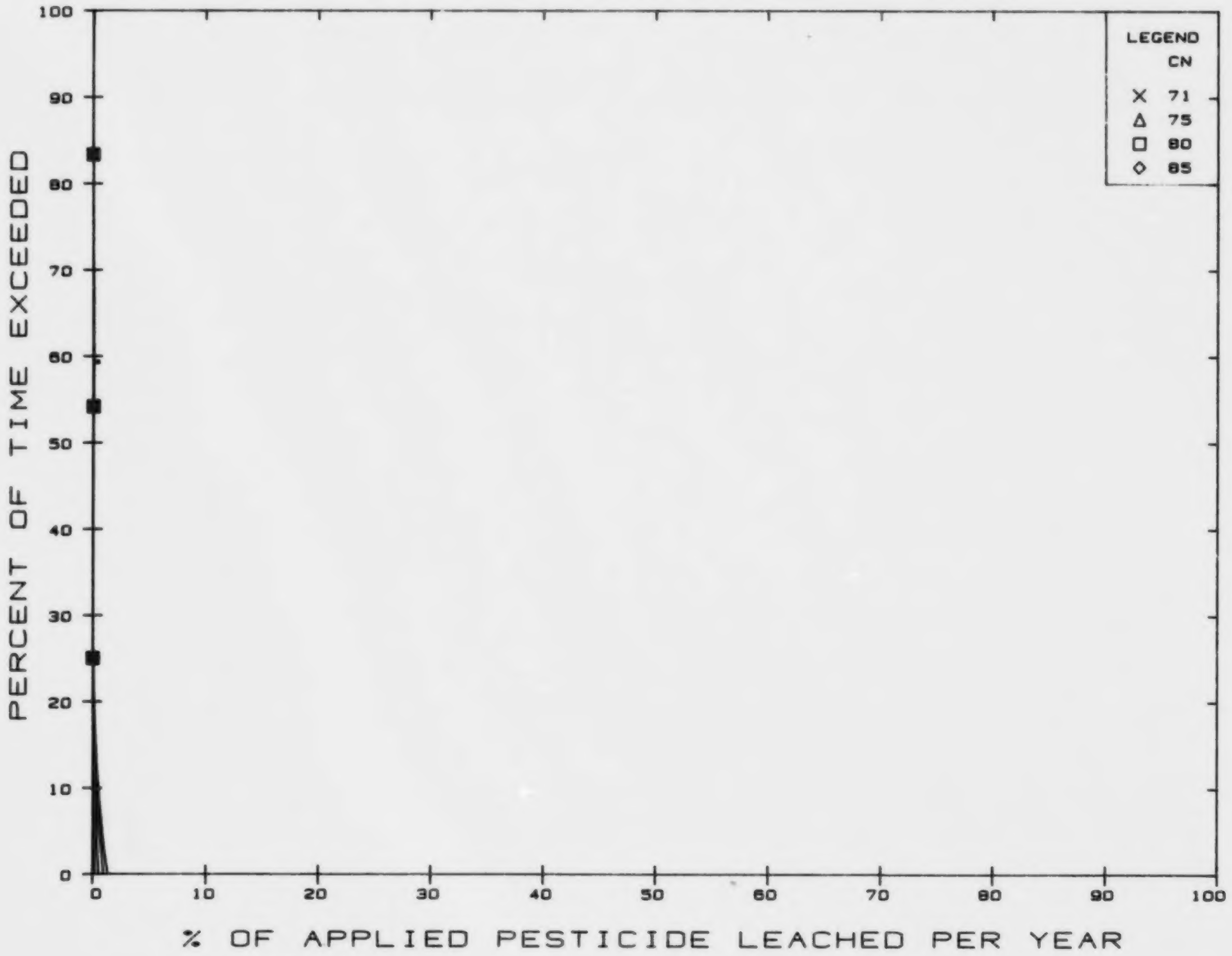


FIGURE A14-9 R=3. KS=.050

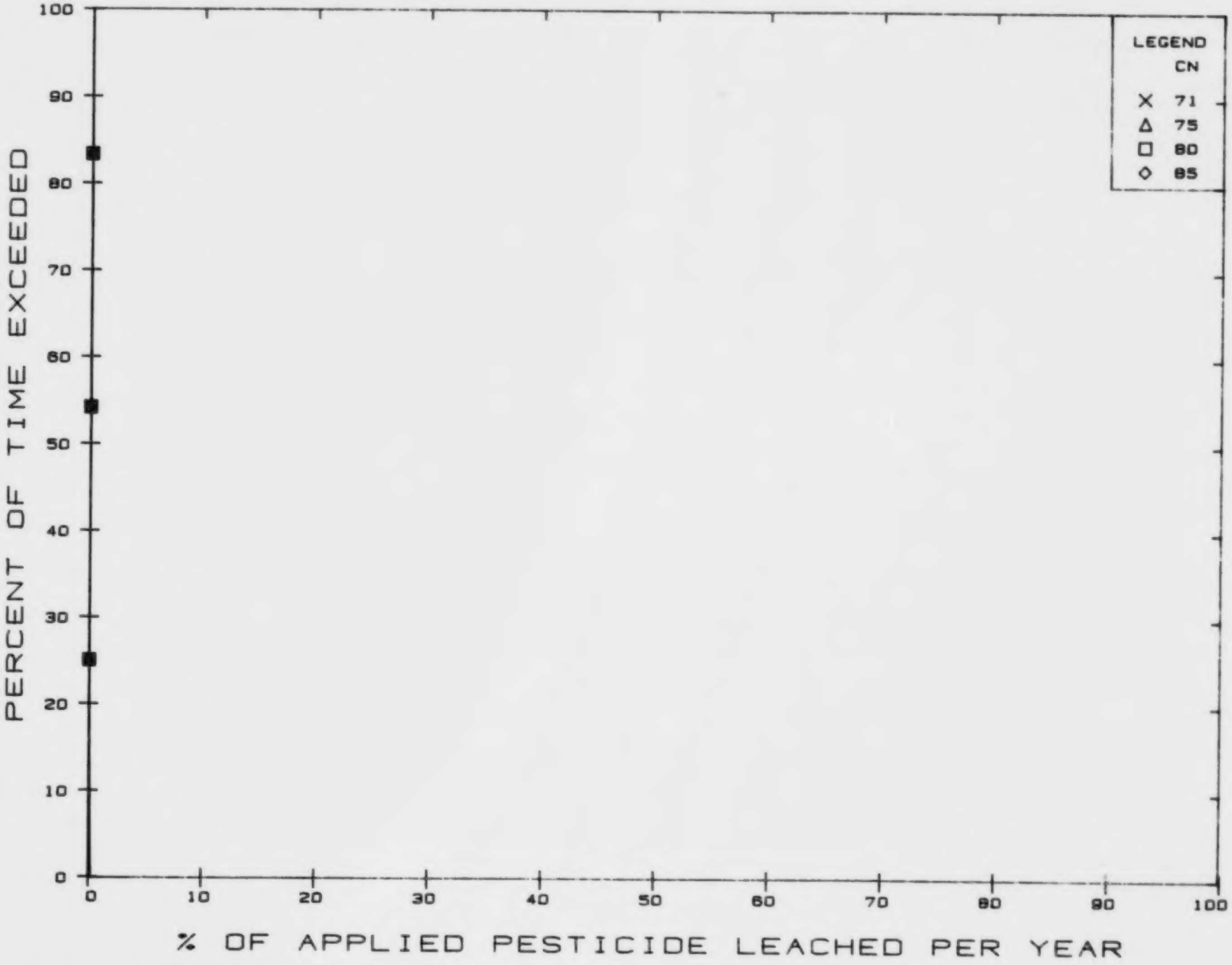


FIGURE A14-10 R=3. KS=.100

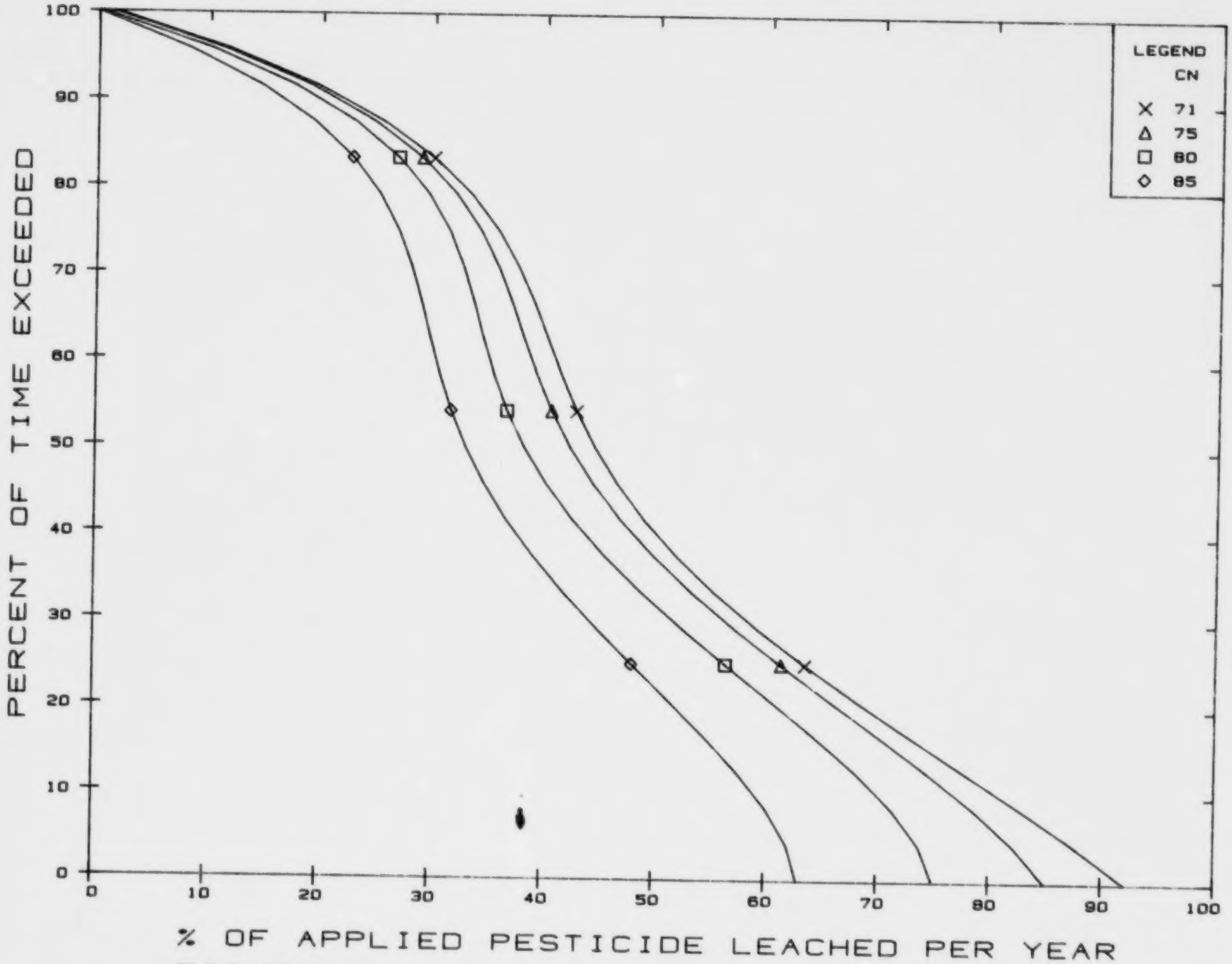


FIGURE A14-11 R=5. KS=.001

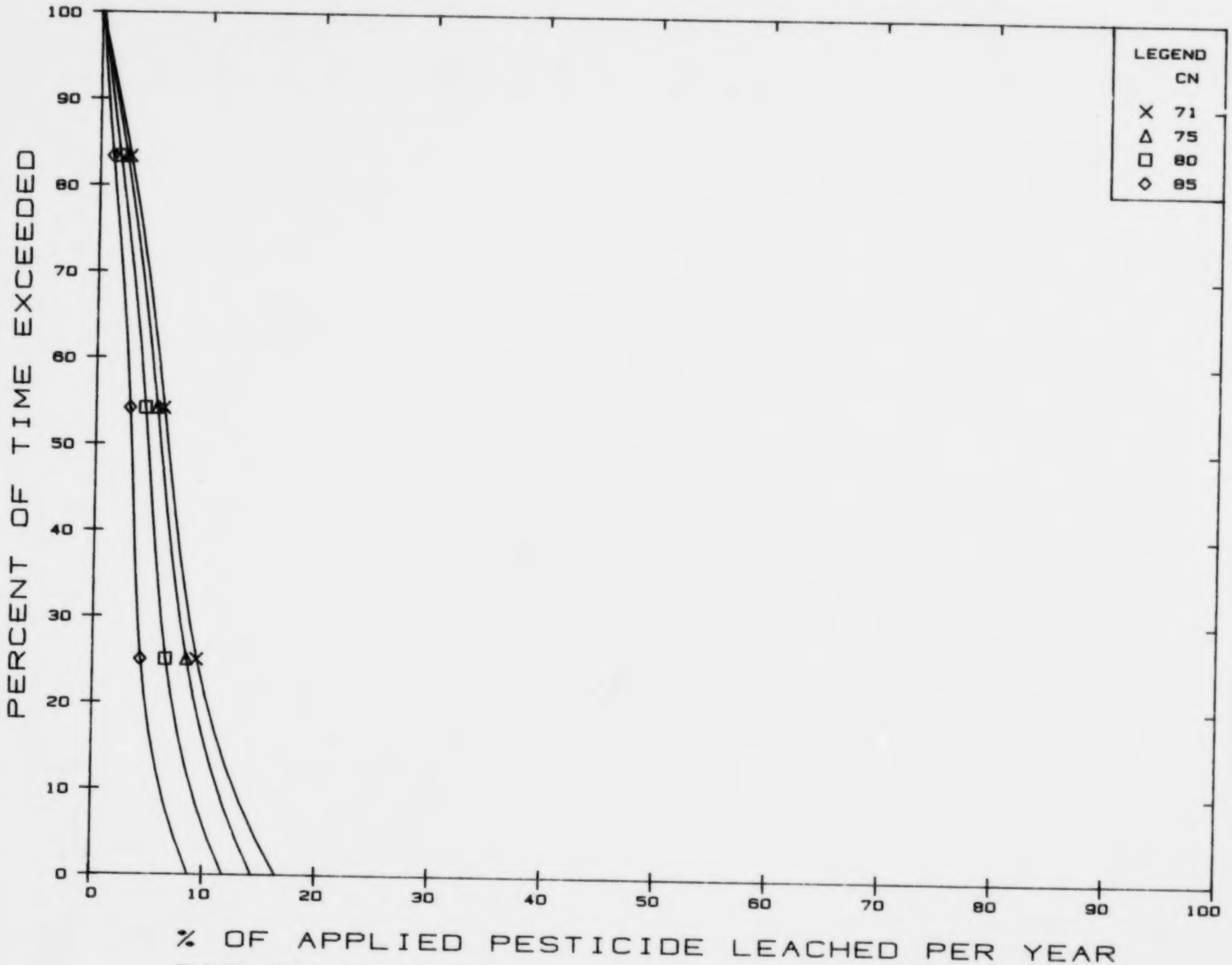


FIGURE A14-12 R=5. KS=.005

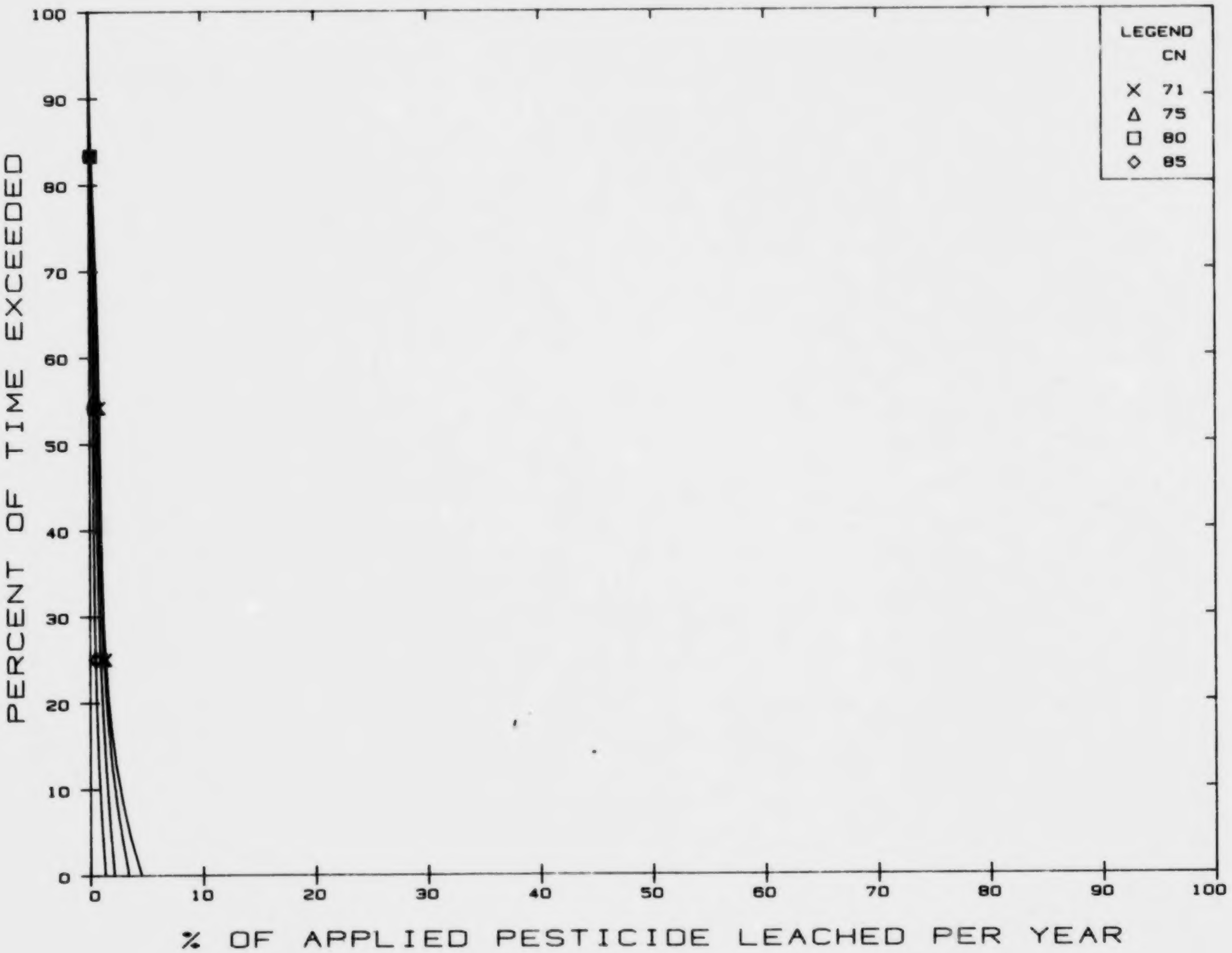


FIGURE A14-13 R=5. KS=.010

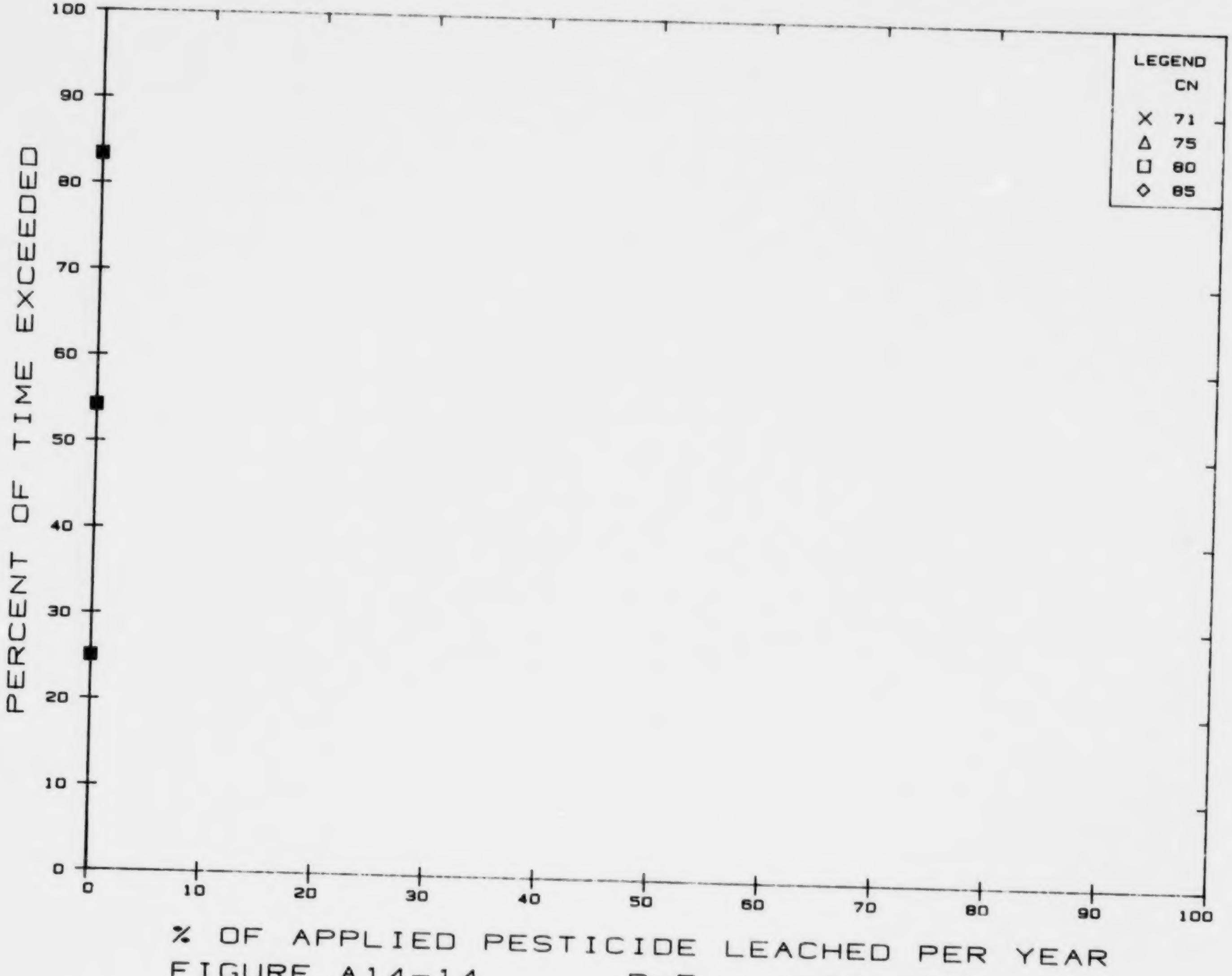


FIGURE A14-14 R=5. KS=.050

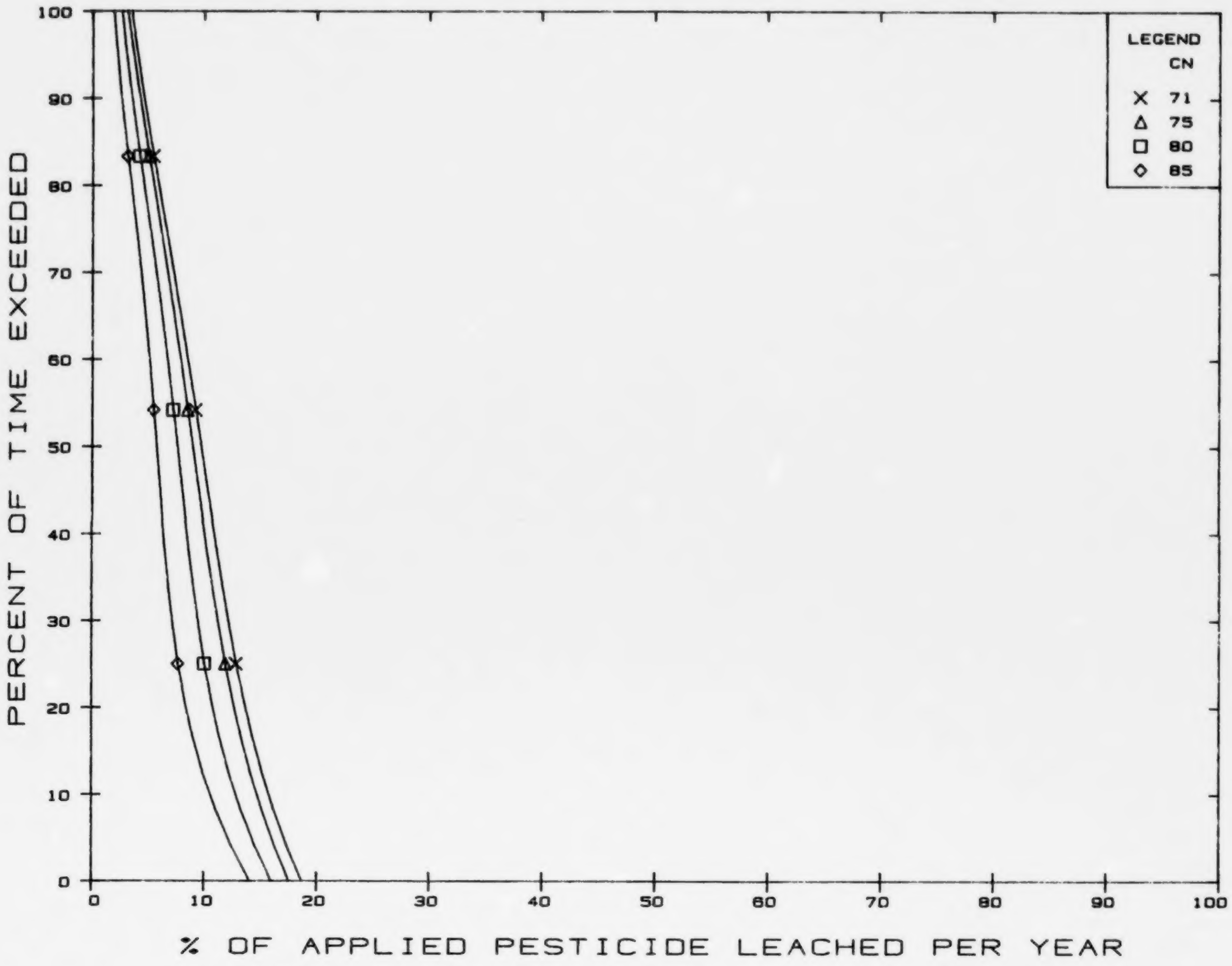


FIGURE A14-15 R=20. KS=.001

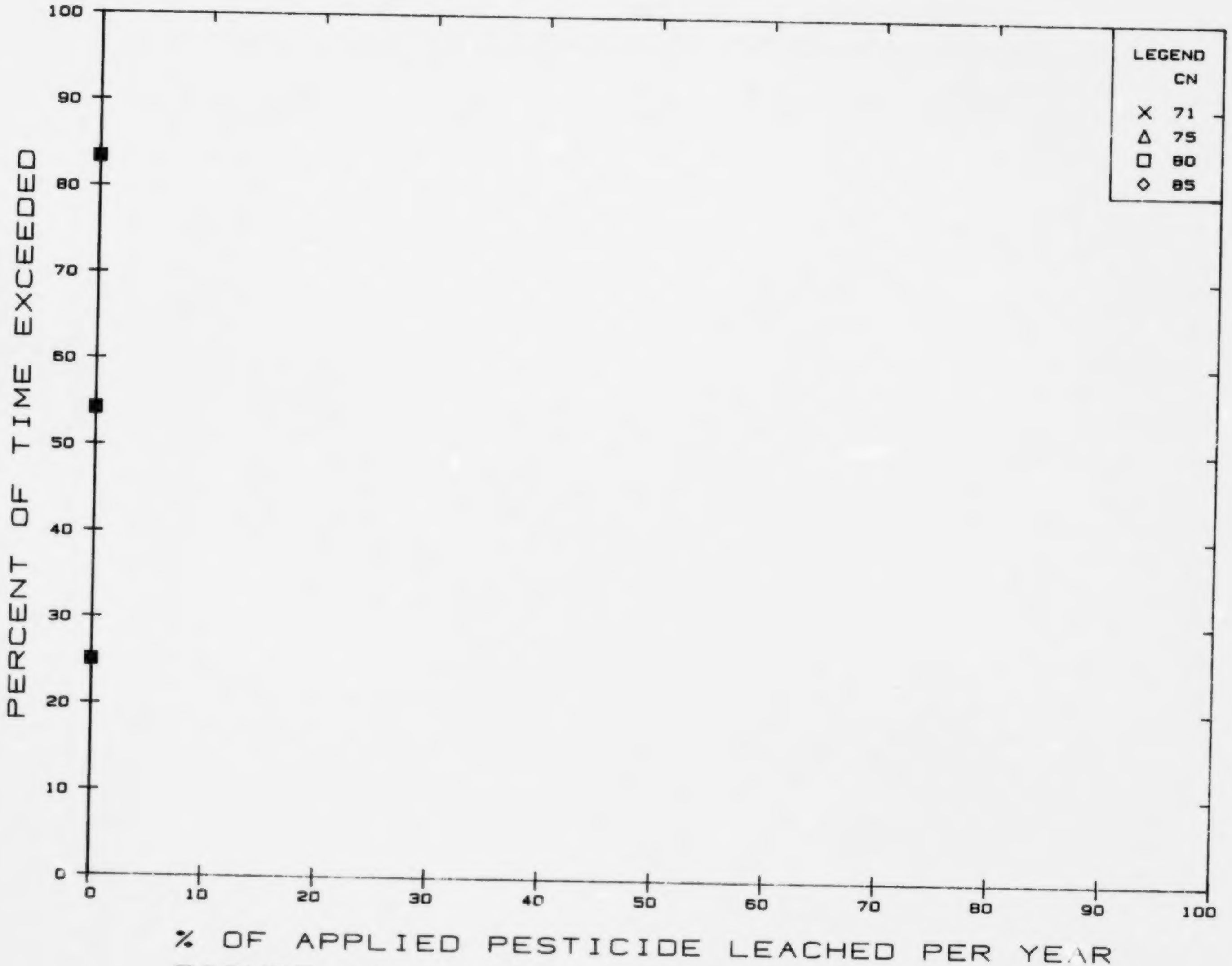


FIGURE A14-16 R=20. KS=.005

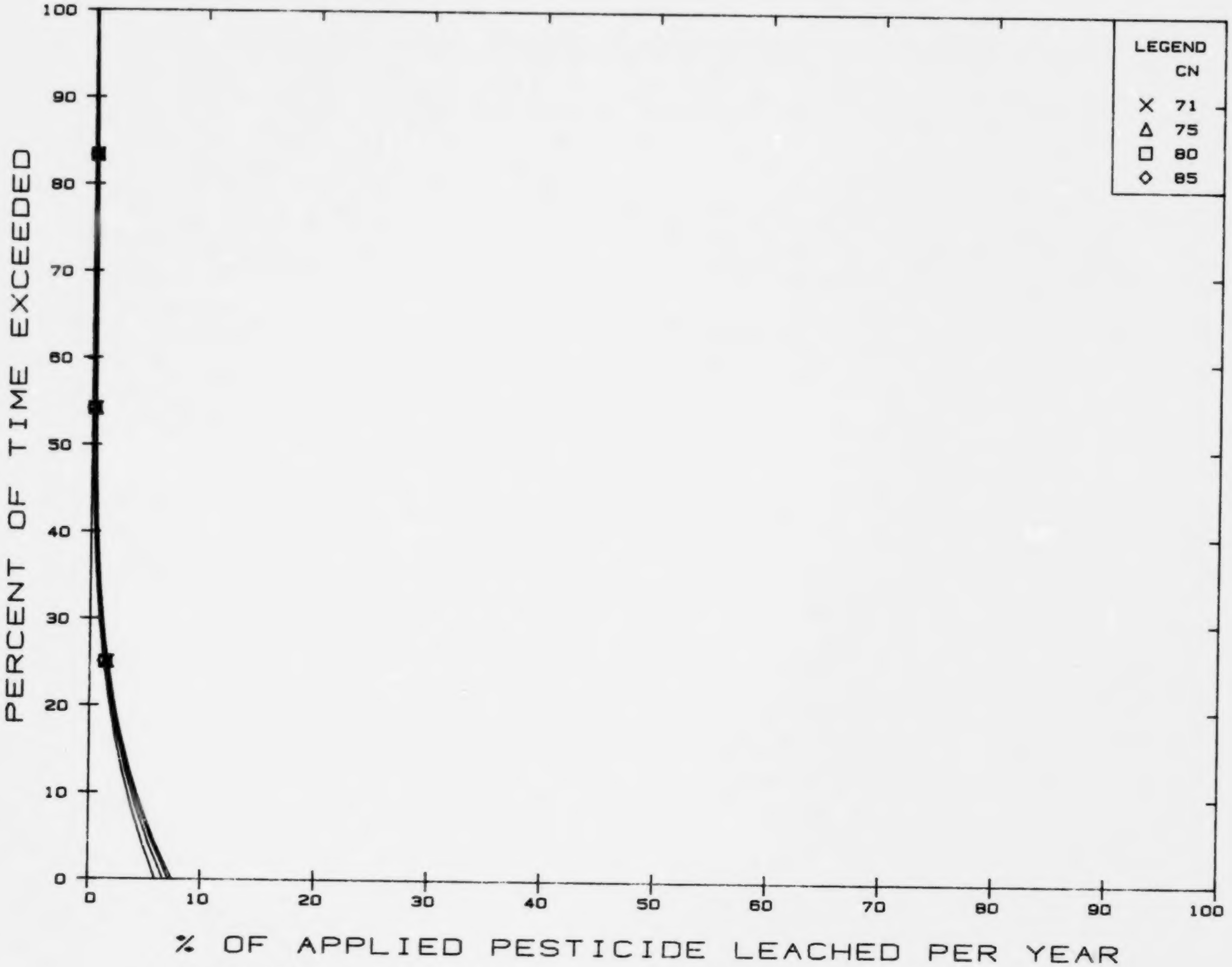


FIGURE A14-17 R=50. KS=.001

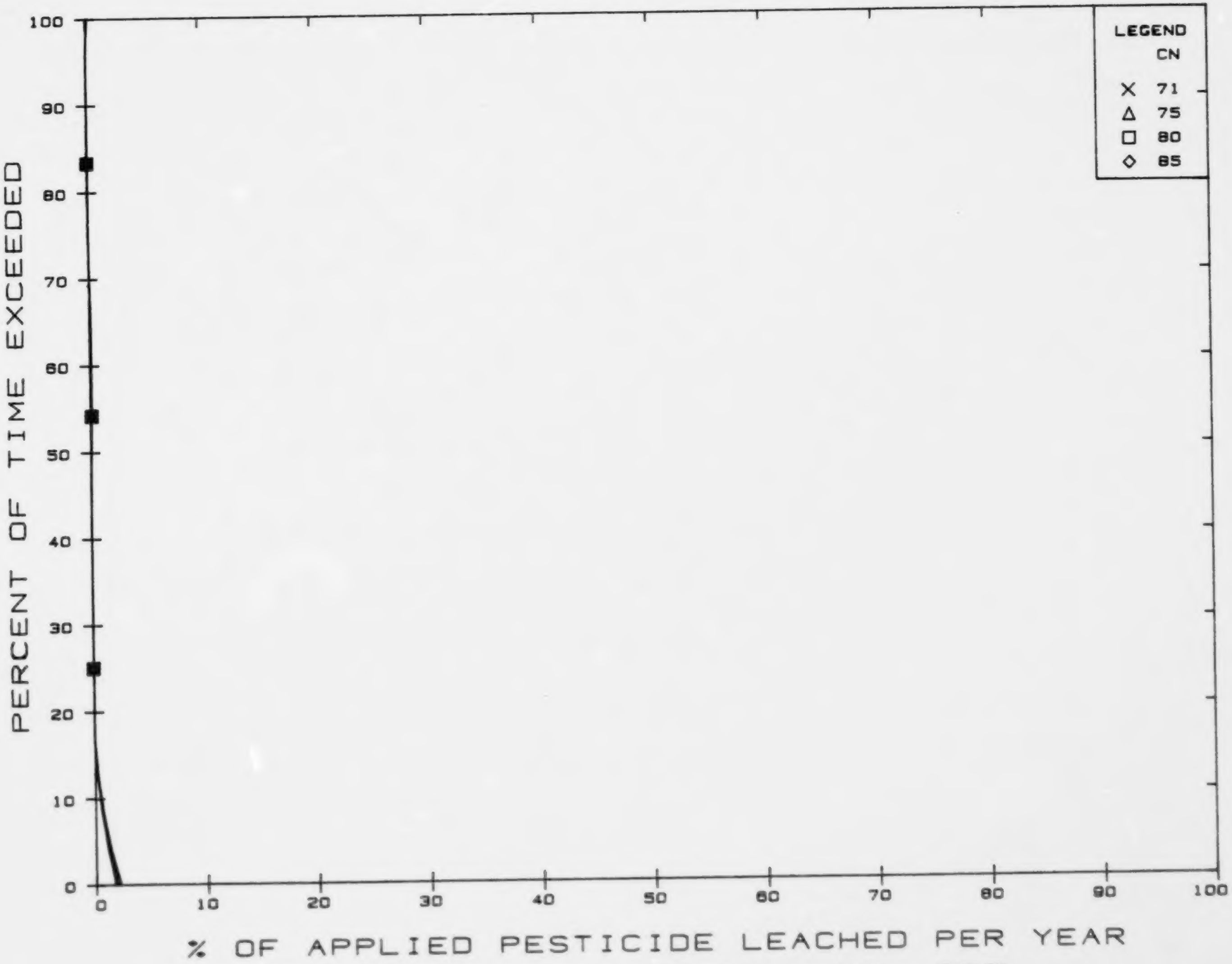


FIGURE A14-18 R=50. KS=.005

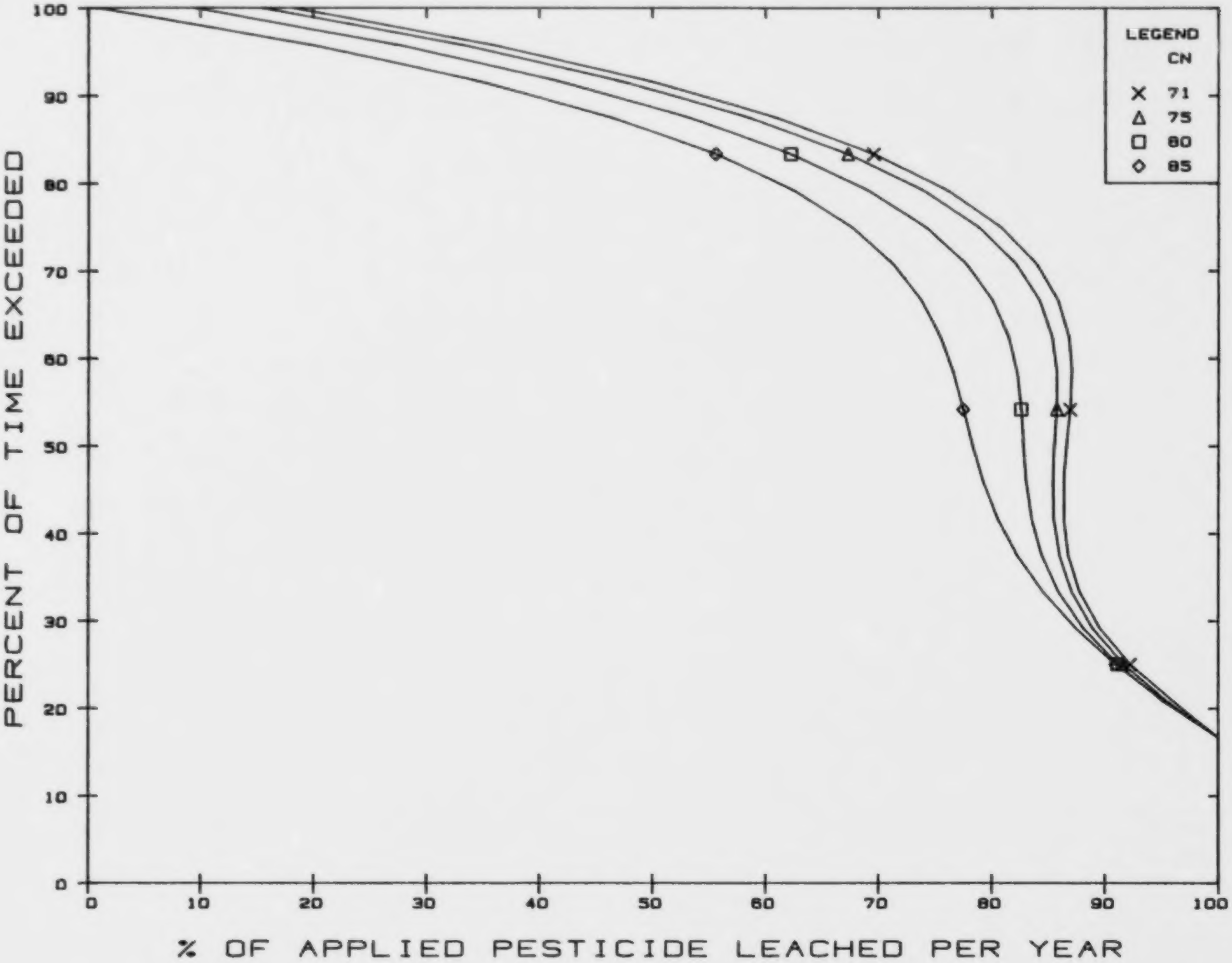


FIGURE A15-1 R=1. KS=.001

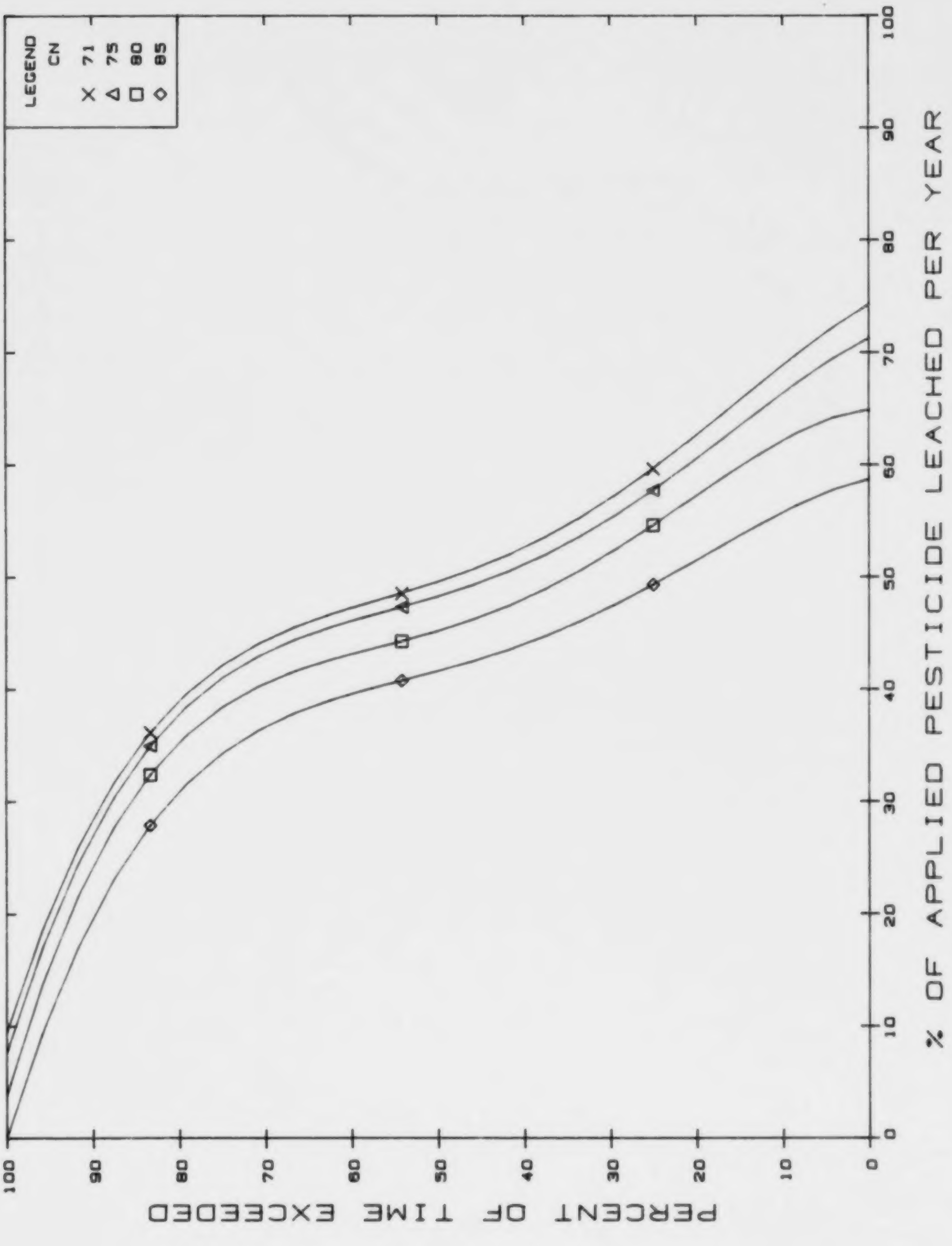


FIGURE A15-2 R=1. KS=.005

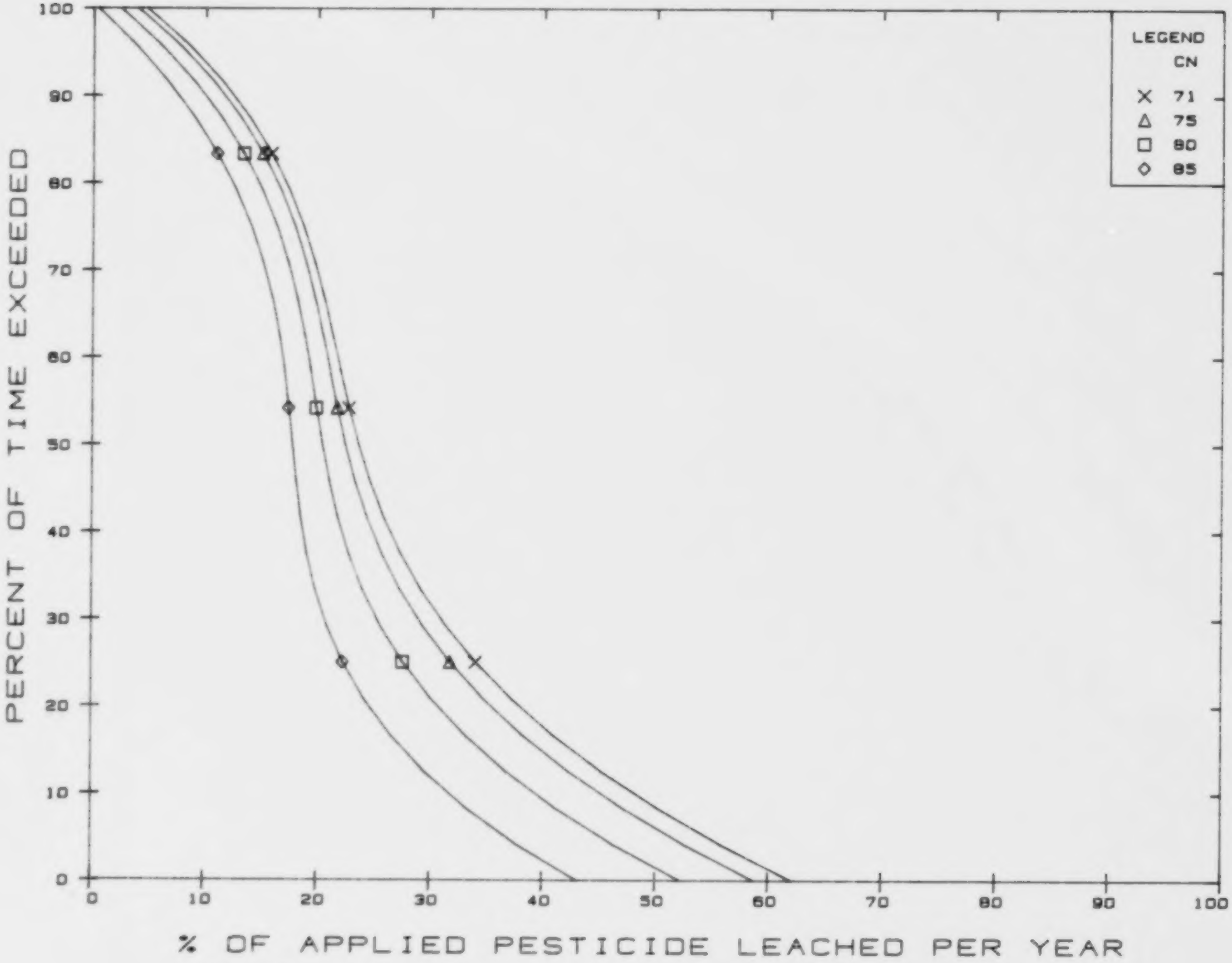


FIGURE A15-3 R=1. KS=.010

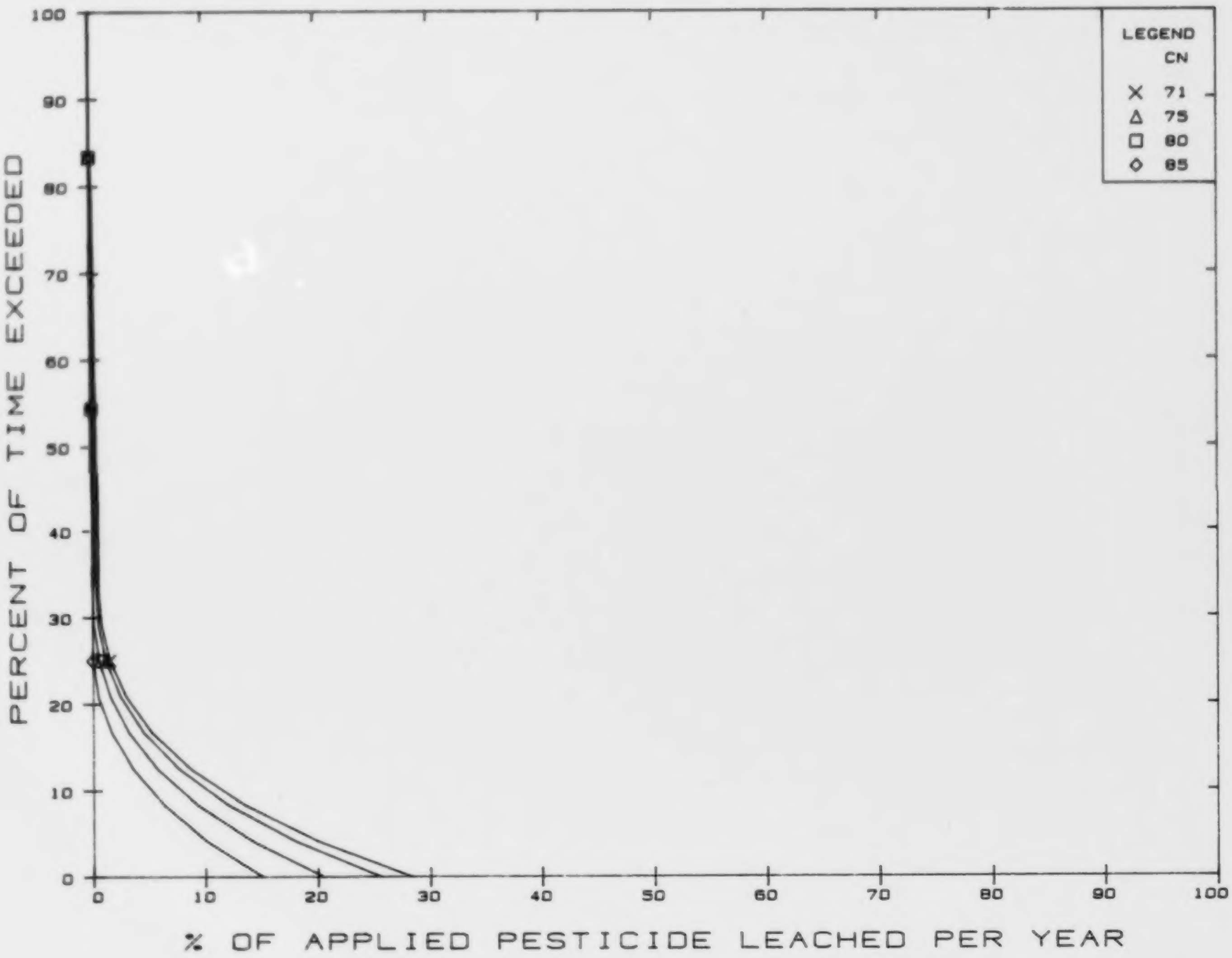


FIGURE A15-4 R=1. KS=.050

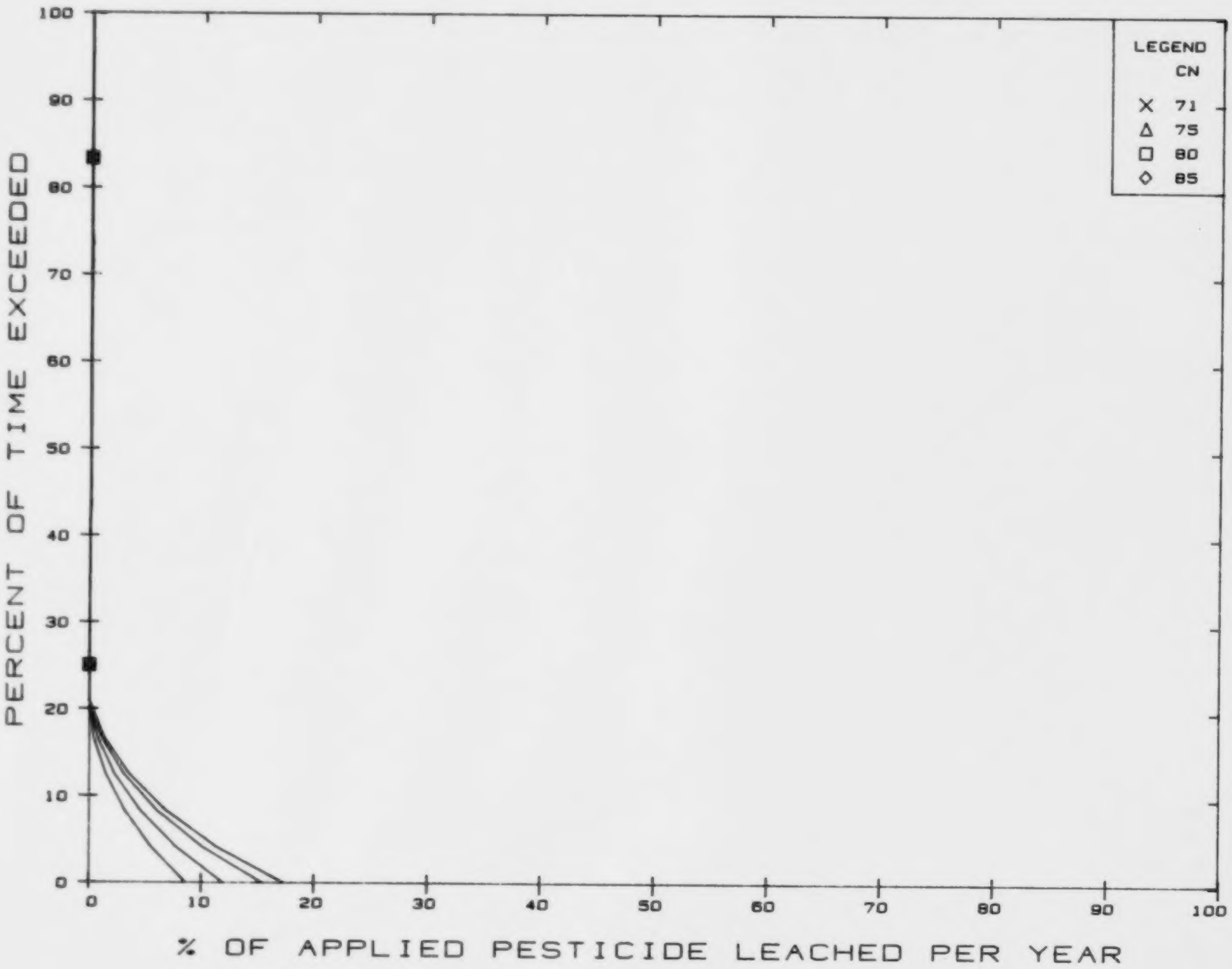


FIGURE A15-5 R=1. KS=.100

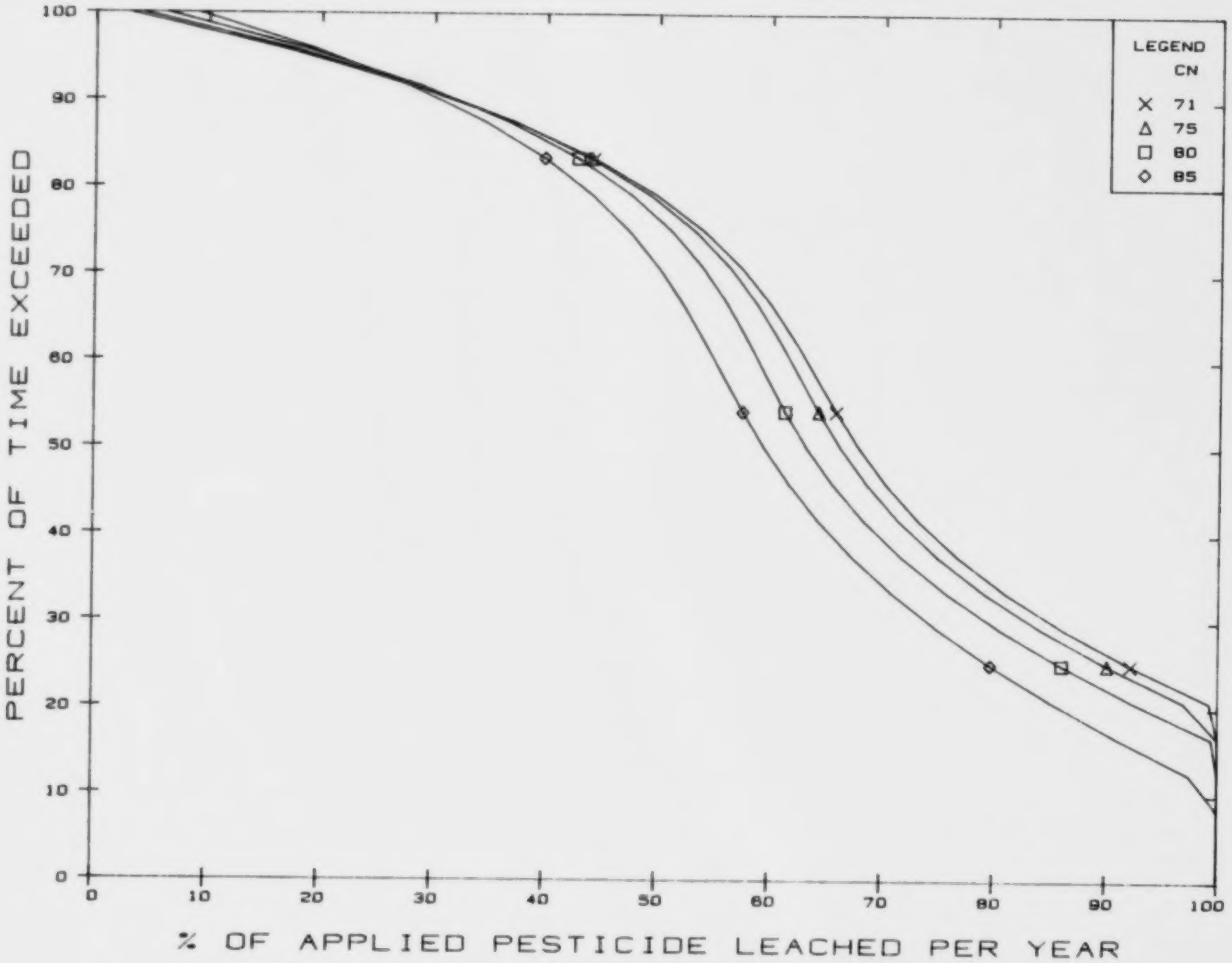


FIGURE A15-6 R=3. KS=.001

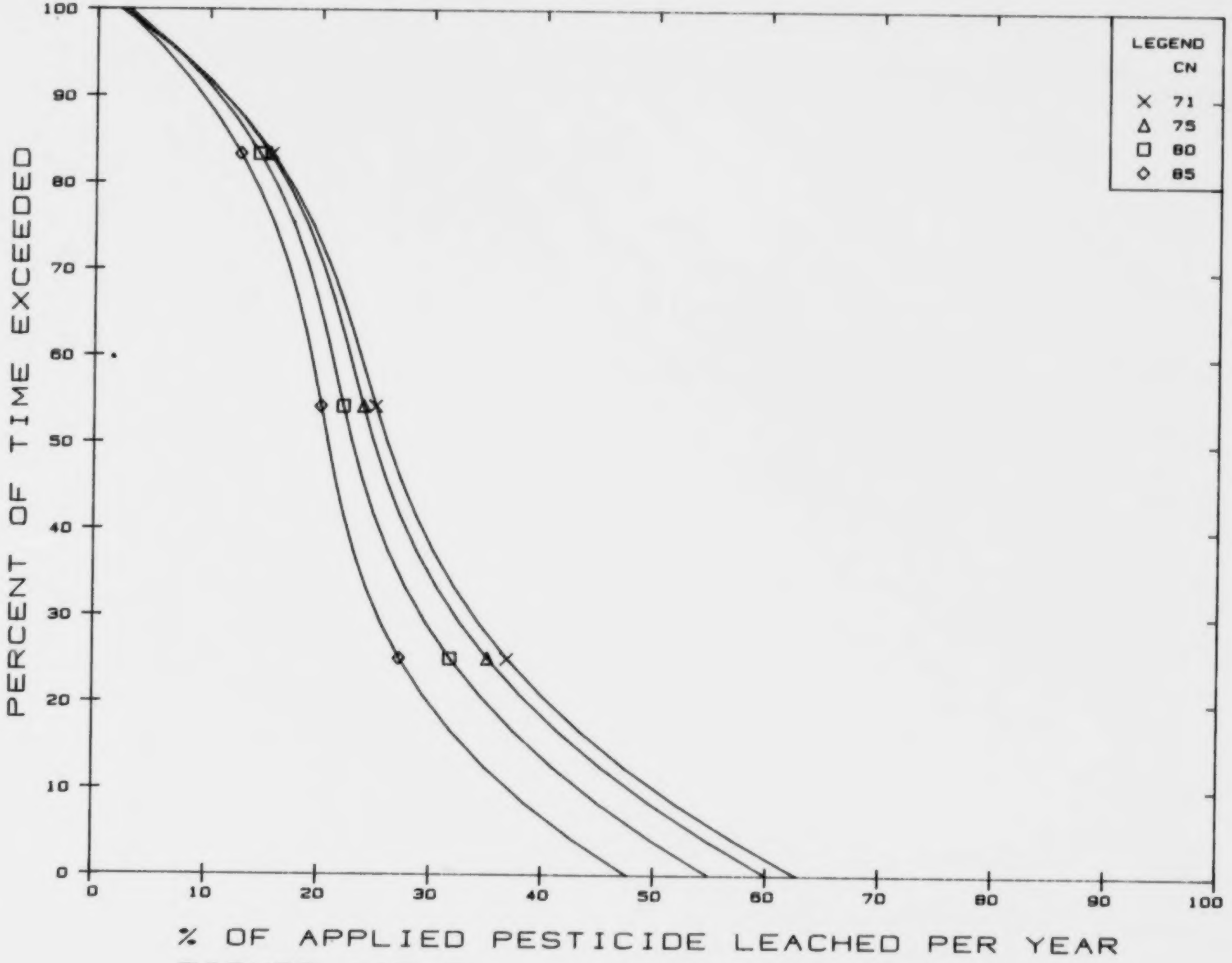


FIGURE A15-7 R=3. KS=.005

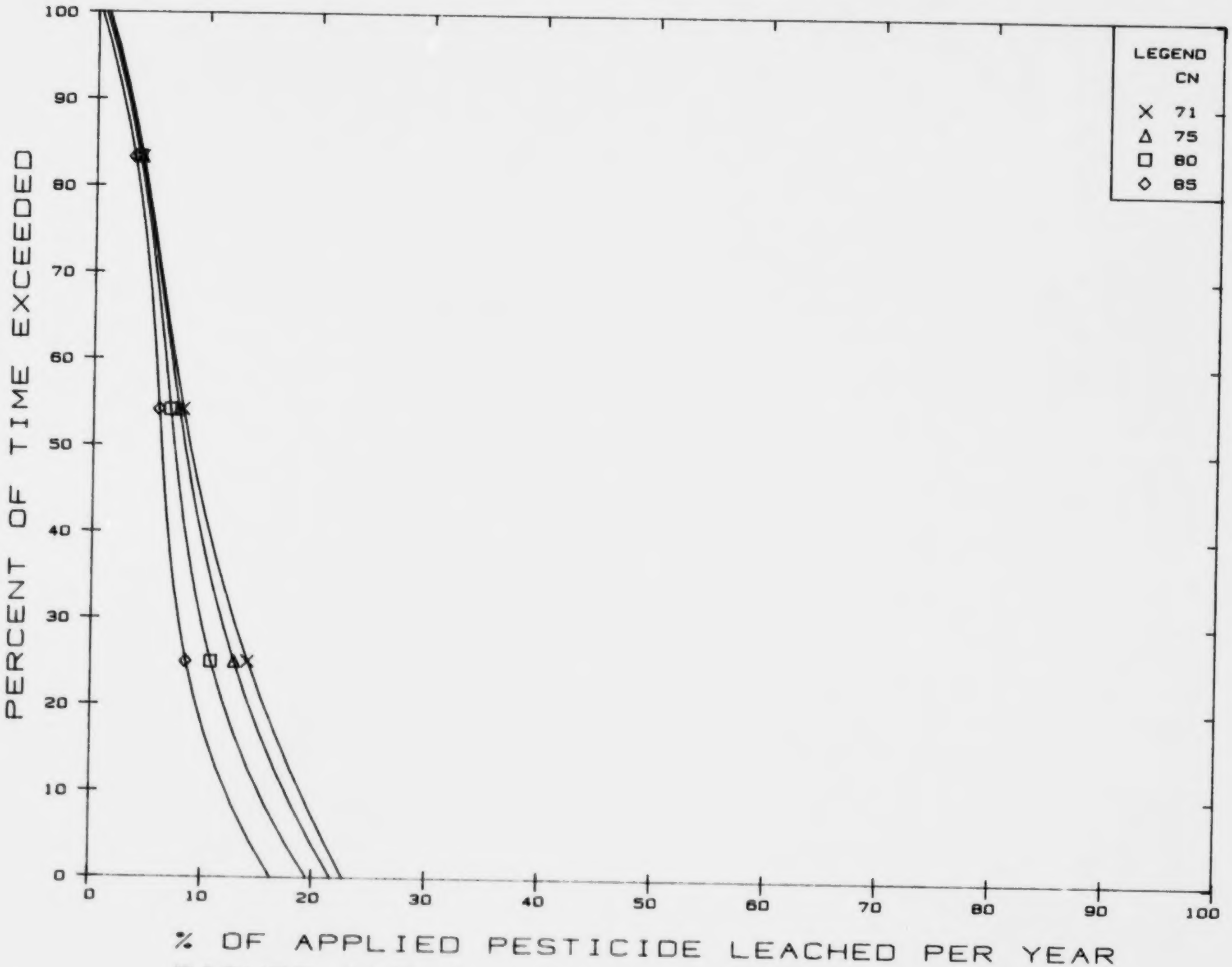


FIGURE A15-8 R=3. KS=.010

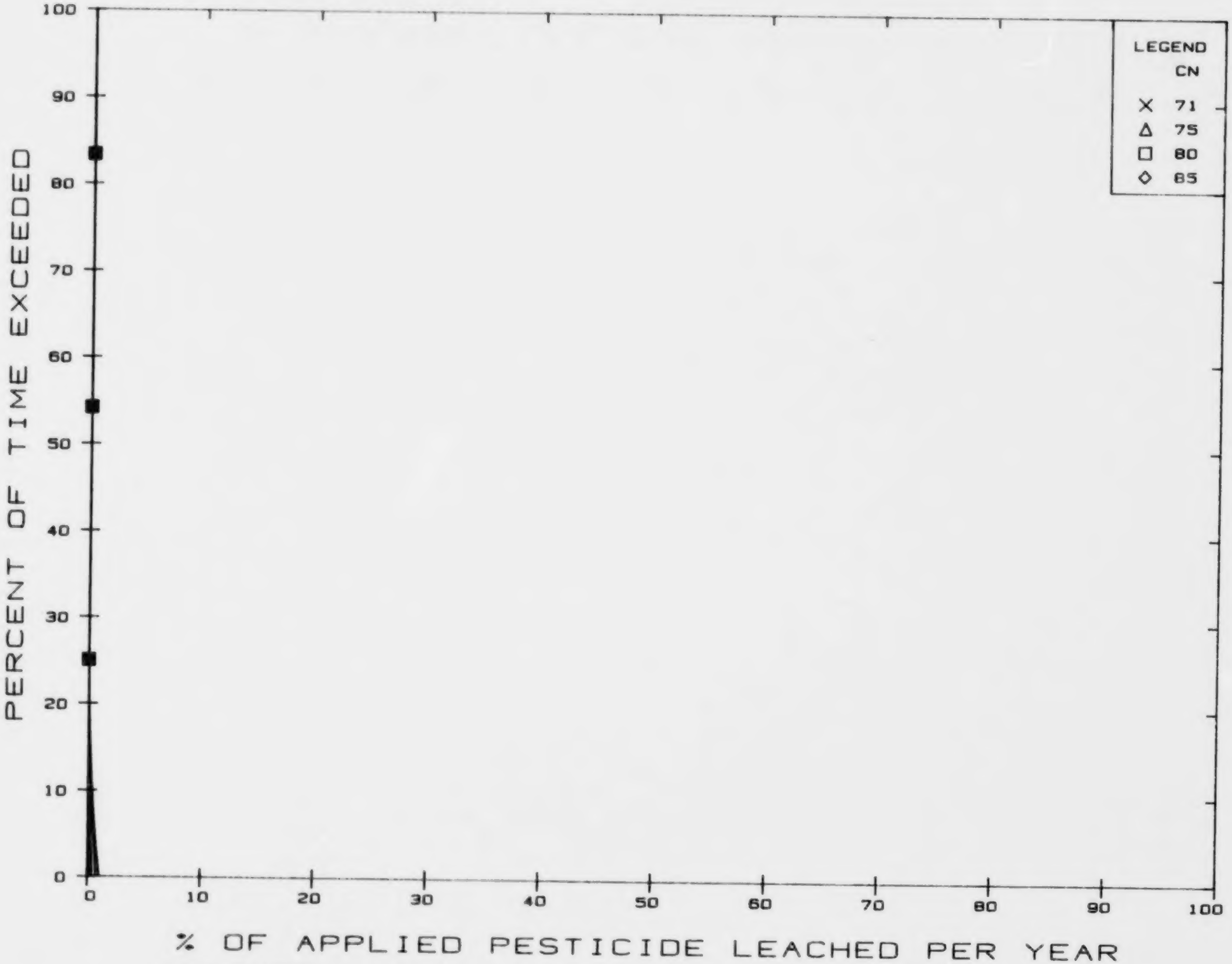


FIGURE A15-9 R=3. KS=.050

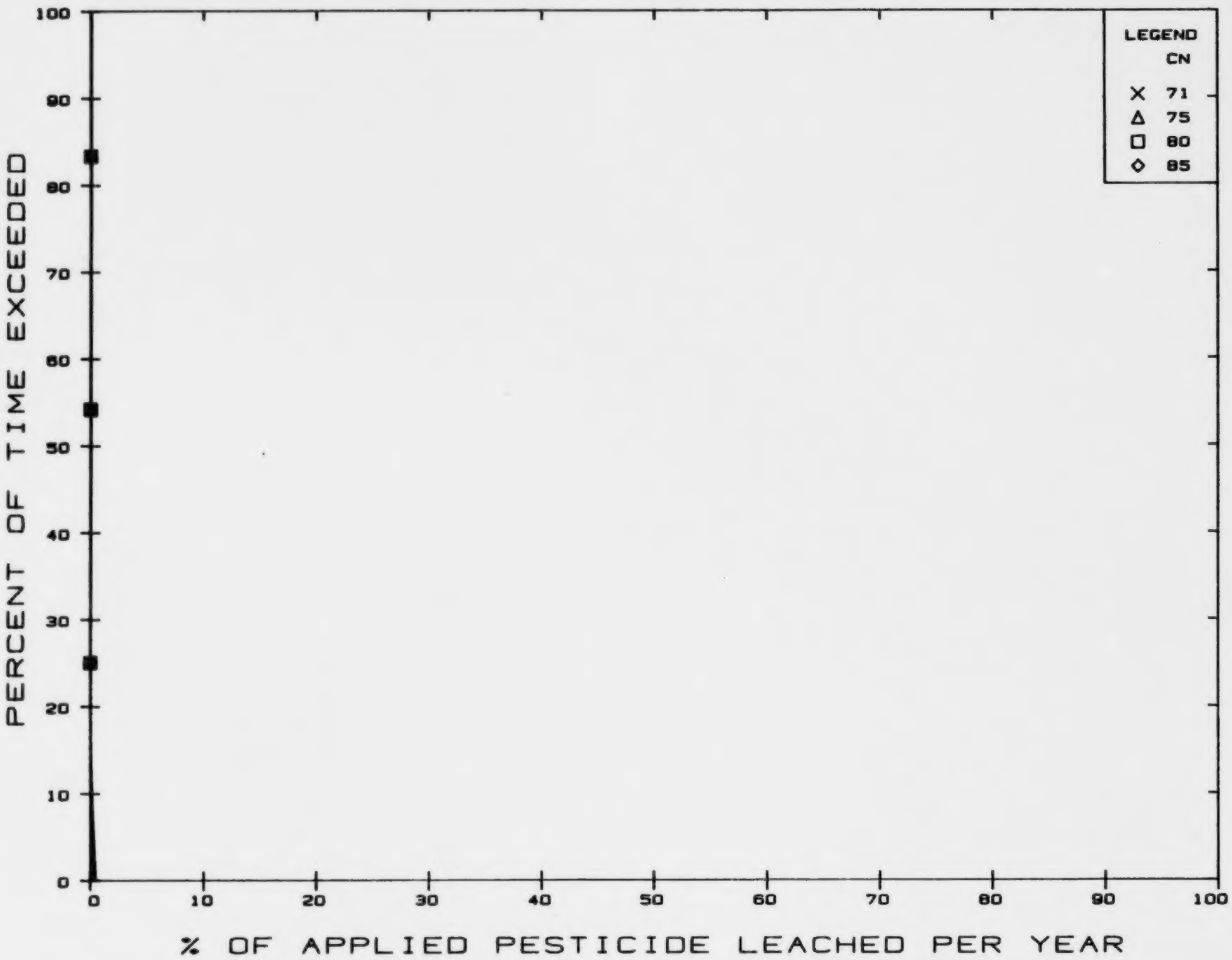


FIGURE A15-10 R=3. KS=.100

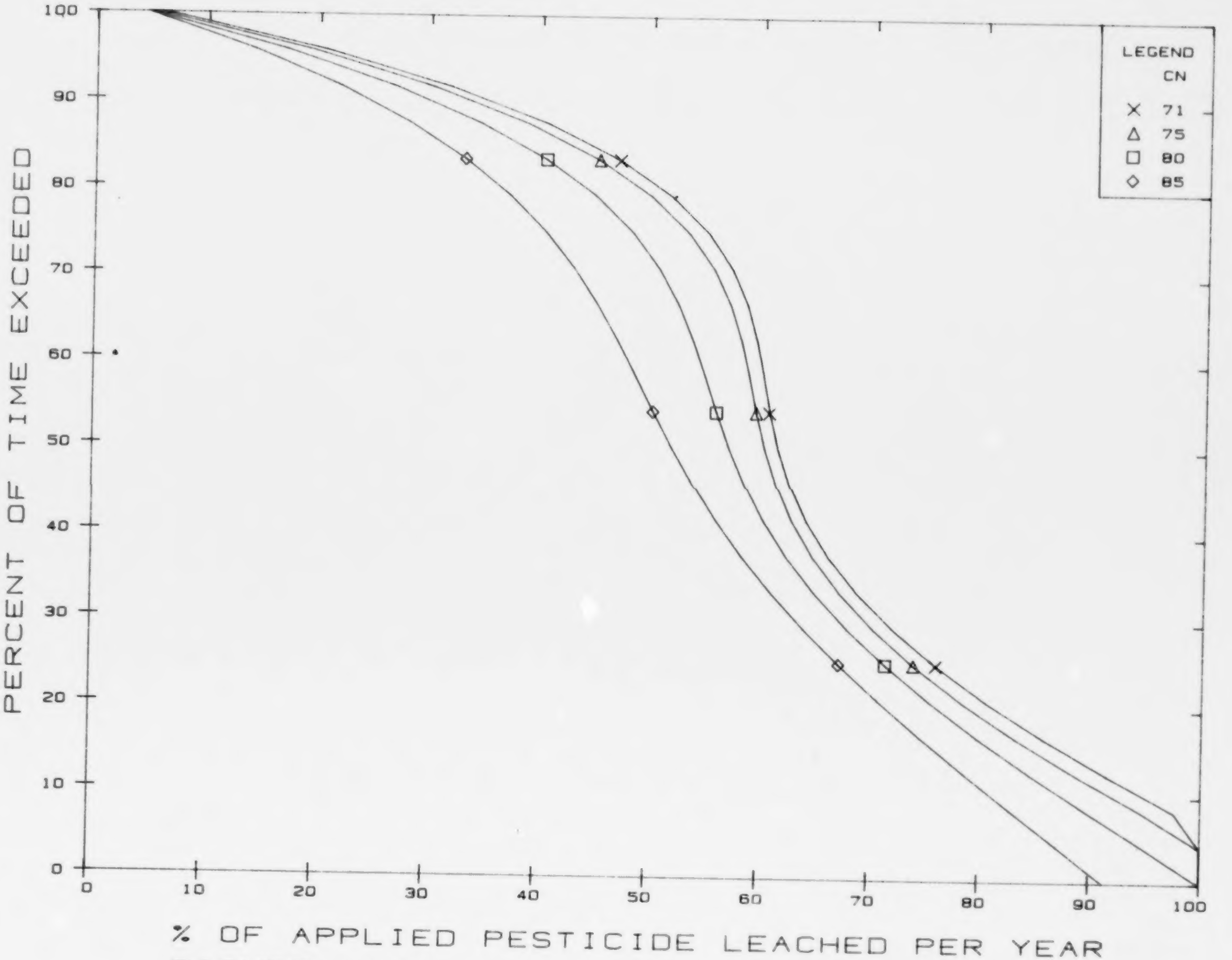


FIGURE A15-11 R=5. KS=.001

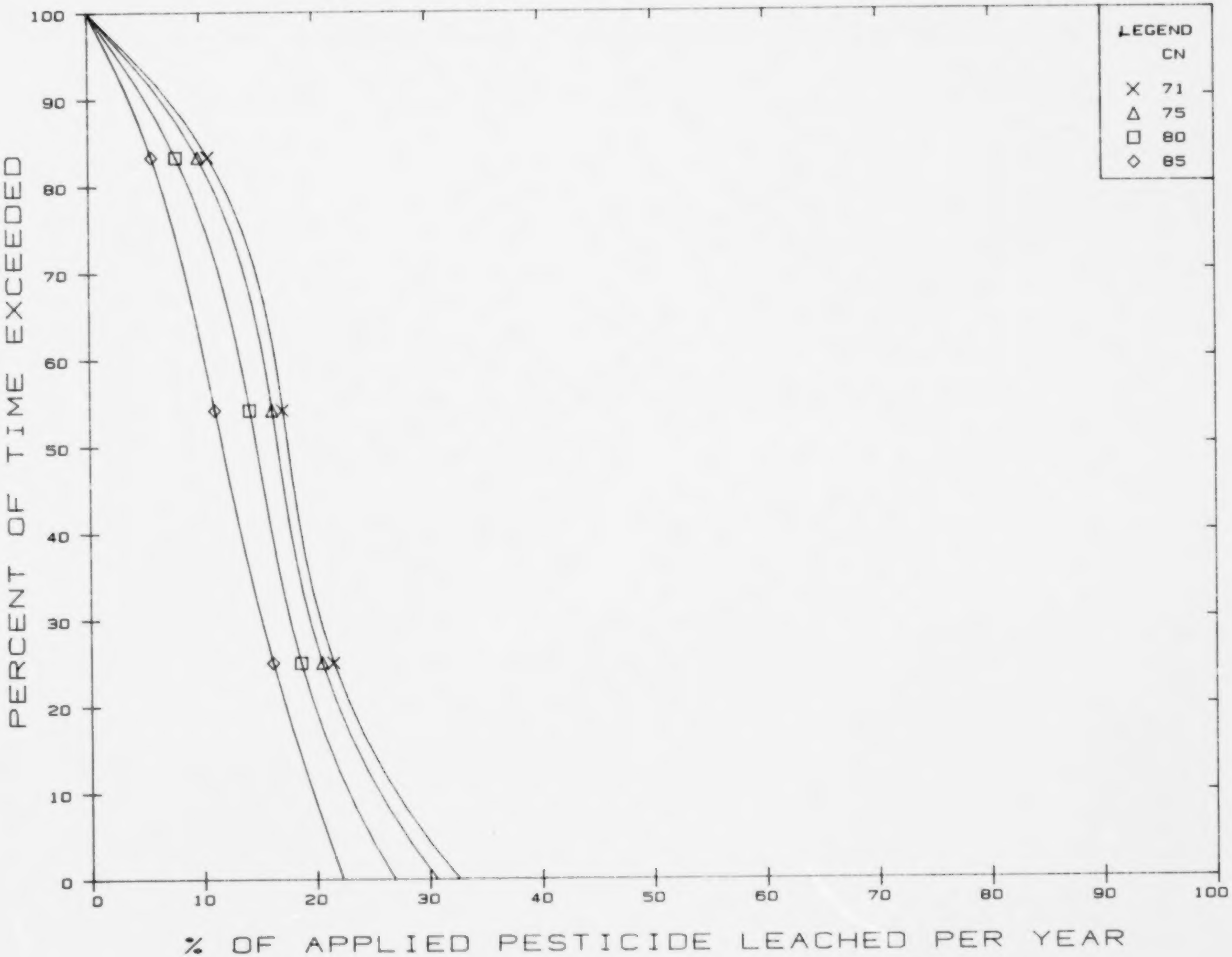


FIGURE A15-12 R=5. KS=.005

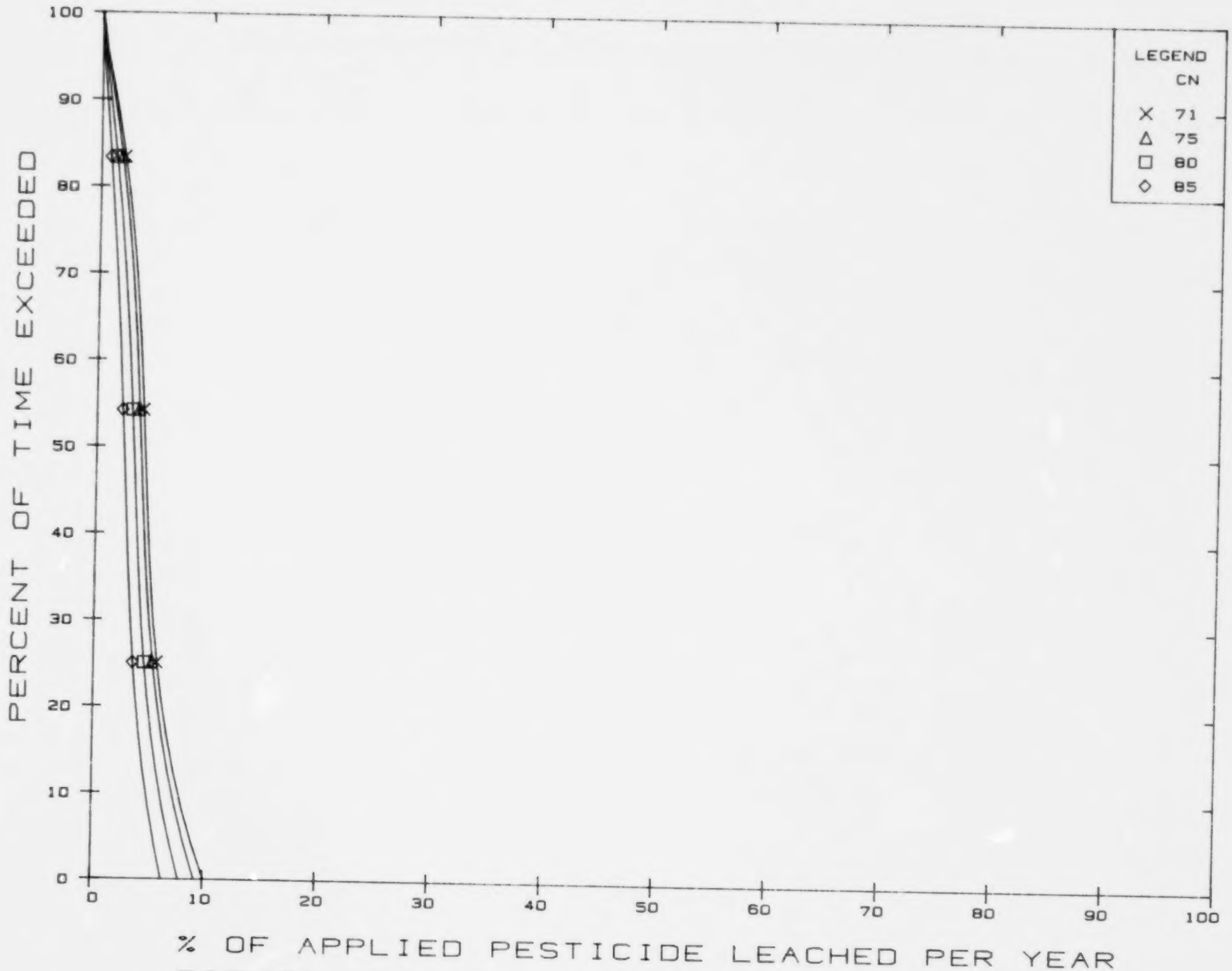


FIGURE A15-13 R=5. KS=.010

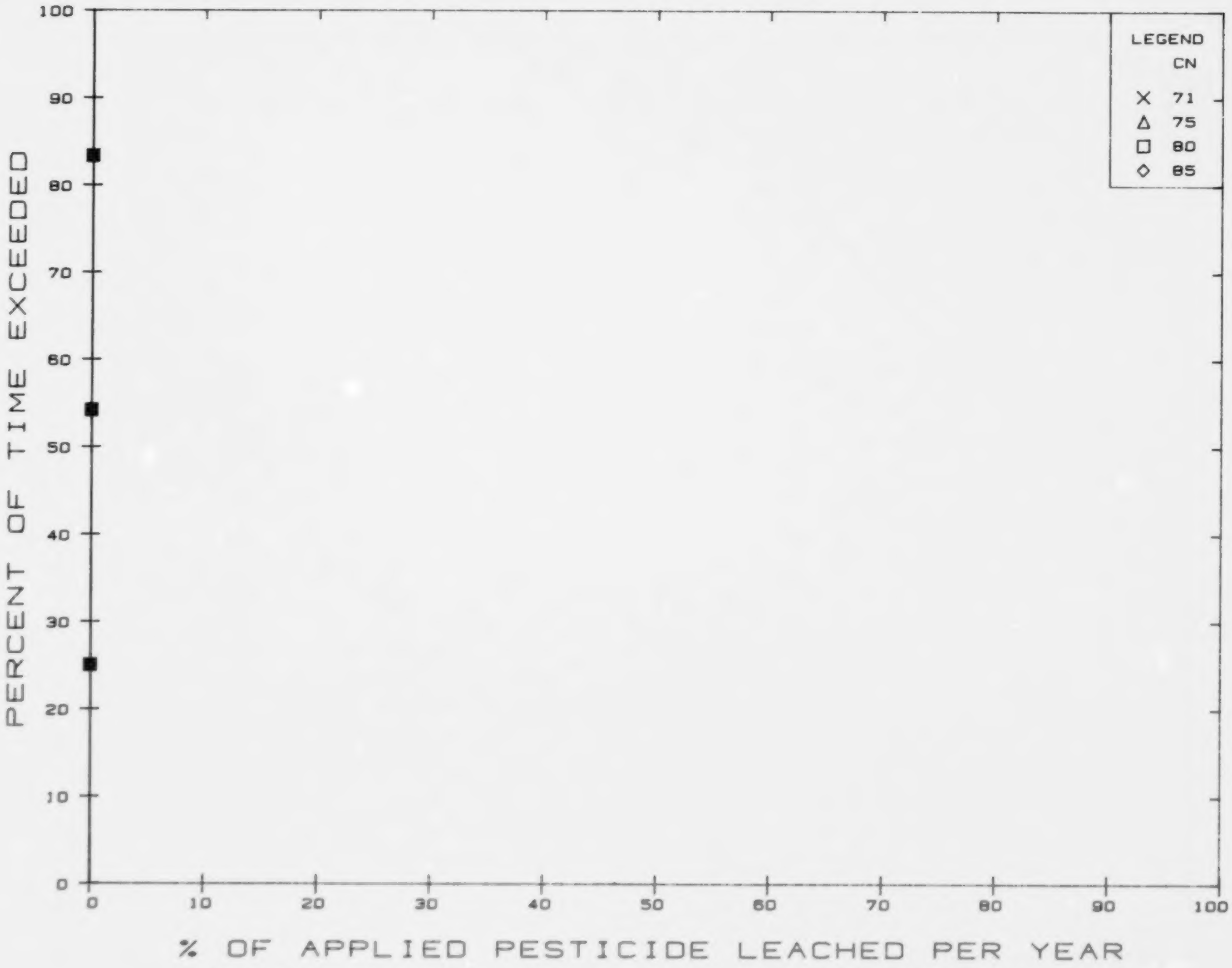


FIGURE A15-14 R=5. KS=.050

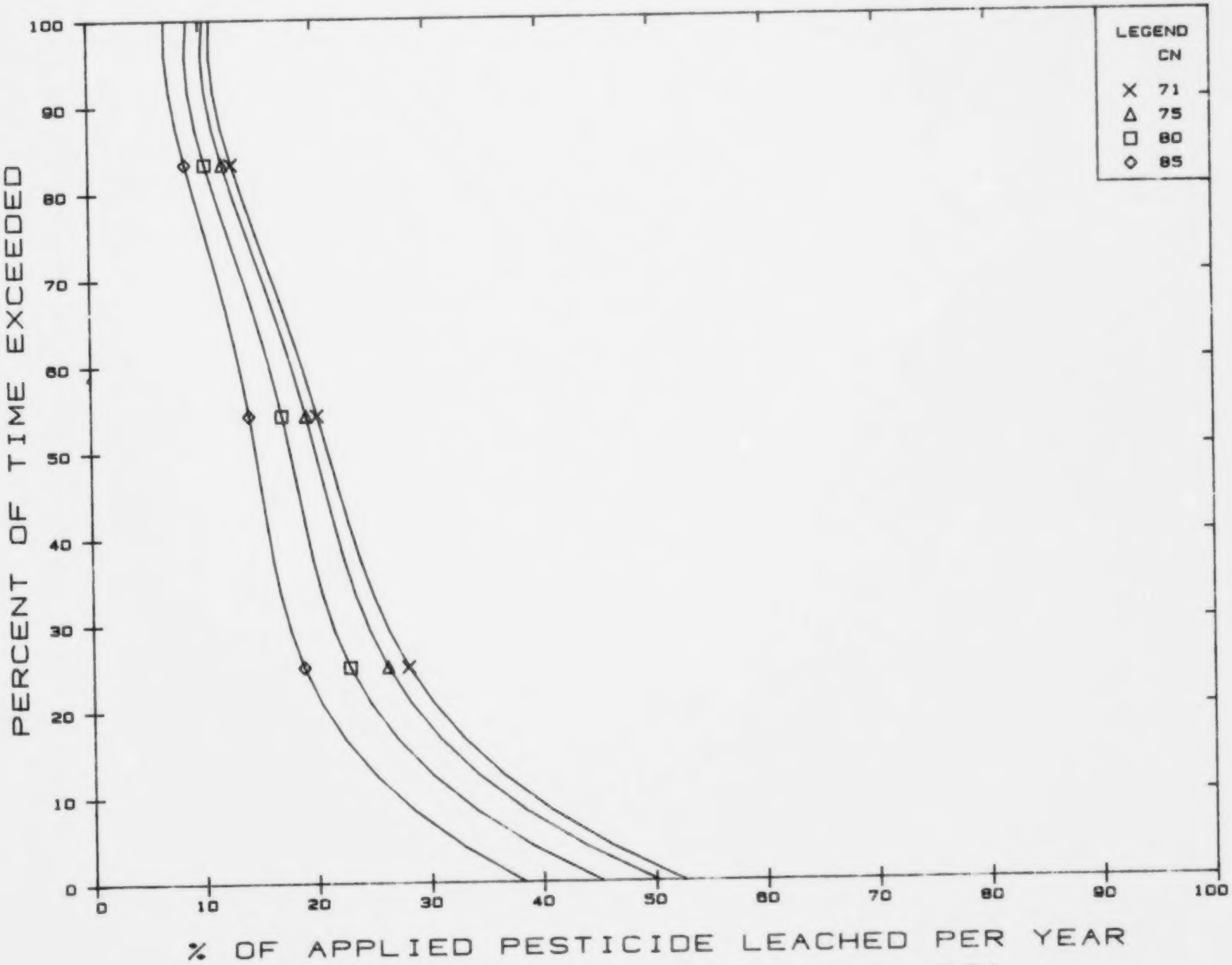


FIGURE A15-15 R=20. KS=.001

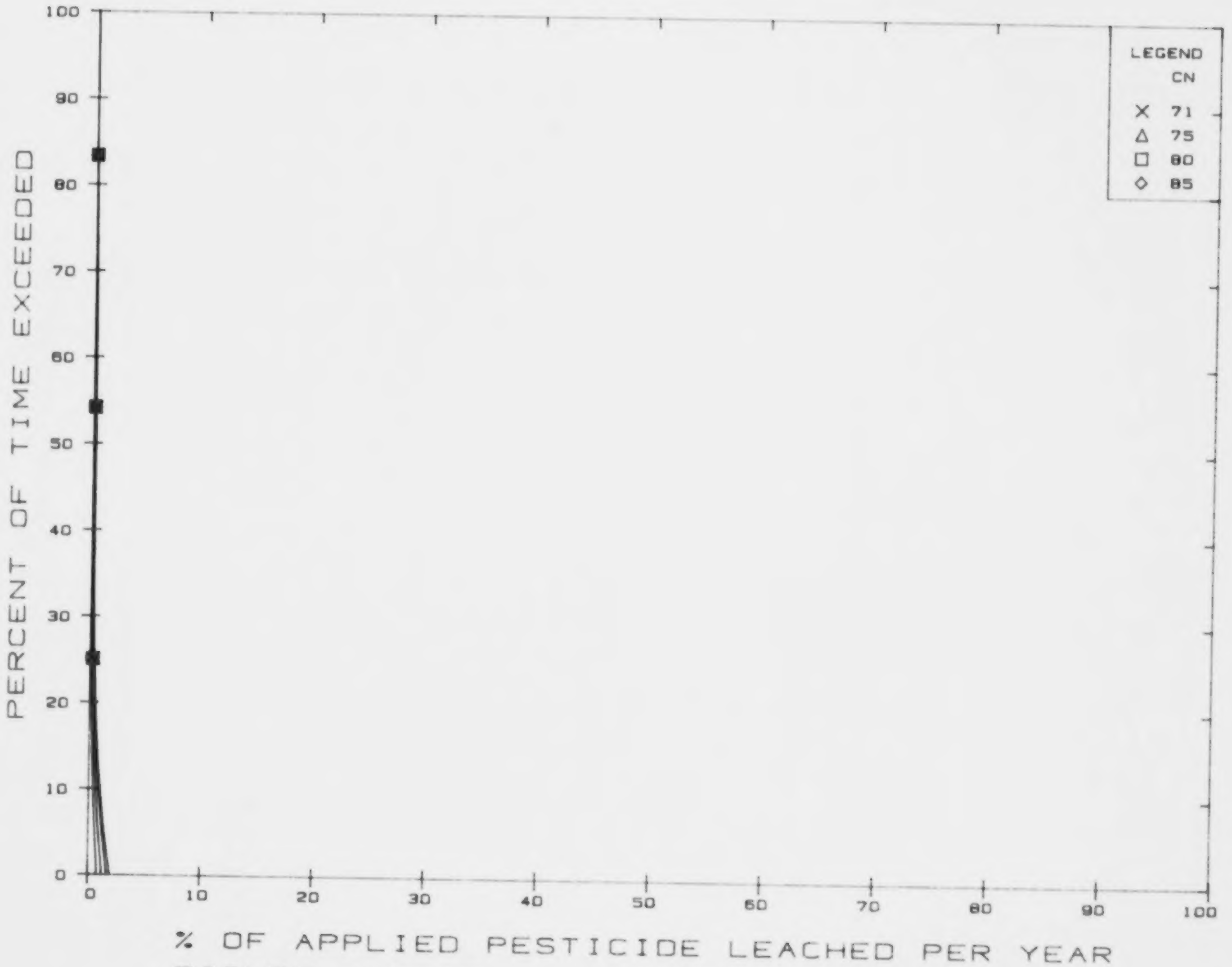


FIGURE A15-16 R=20. KS=.005

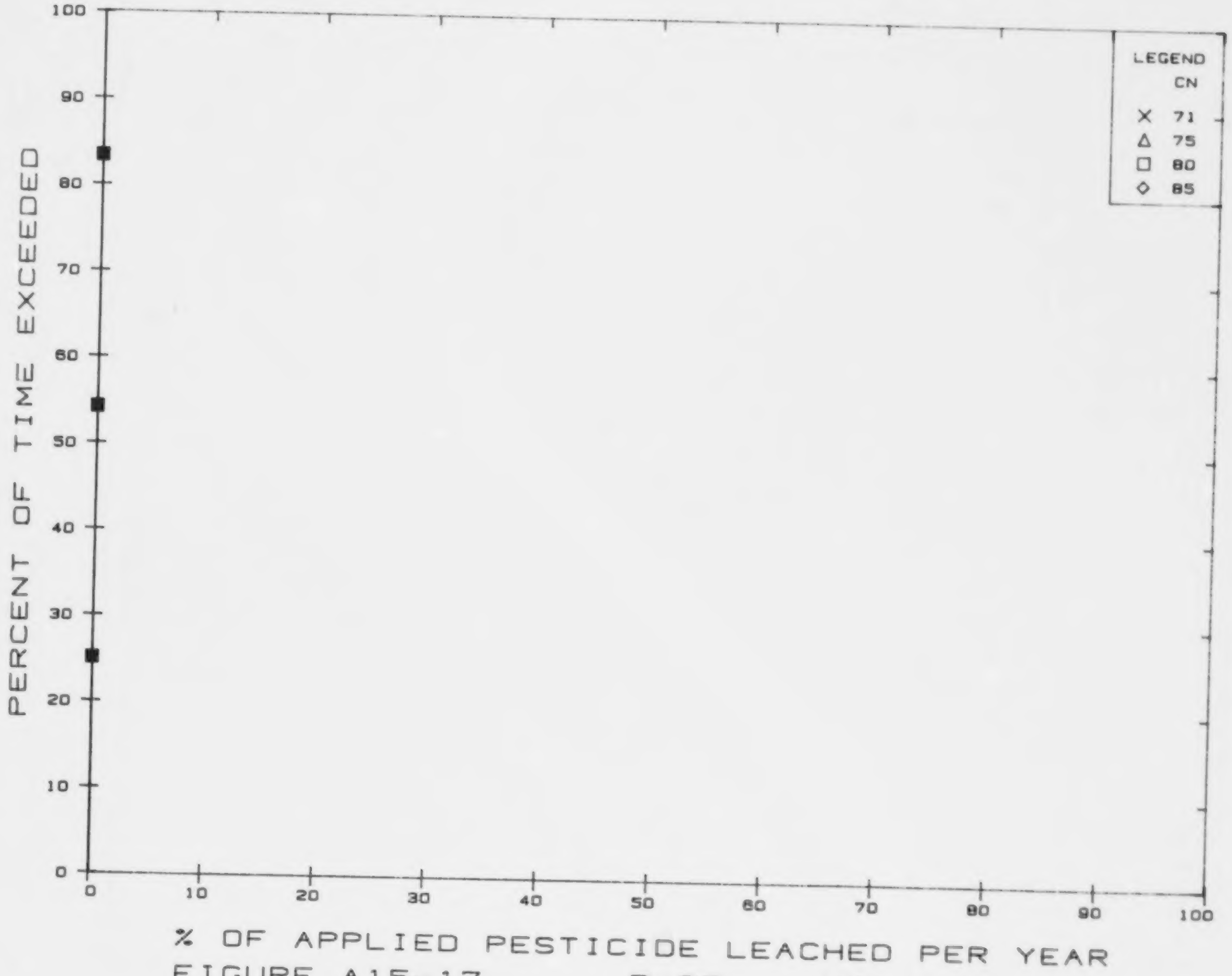


FIGURE A15-17 R=20. KS=.010

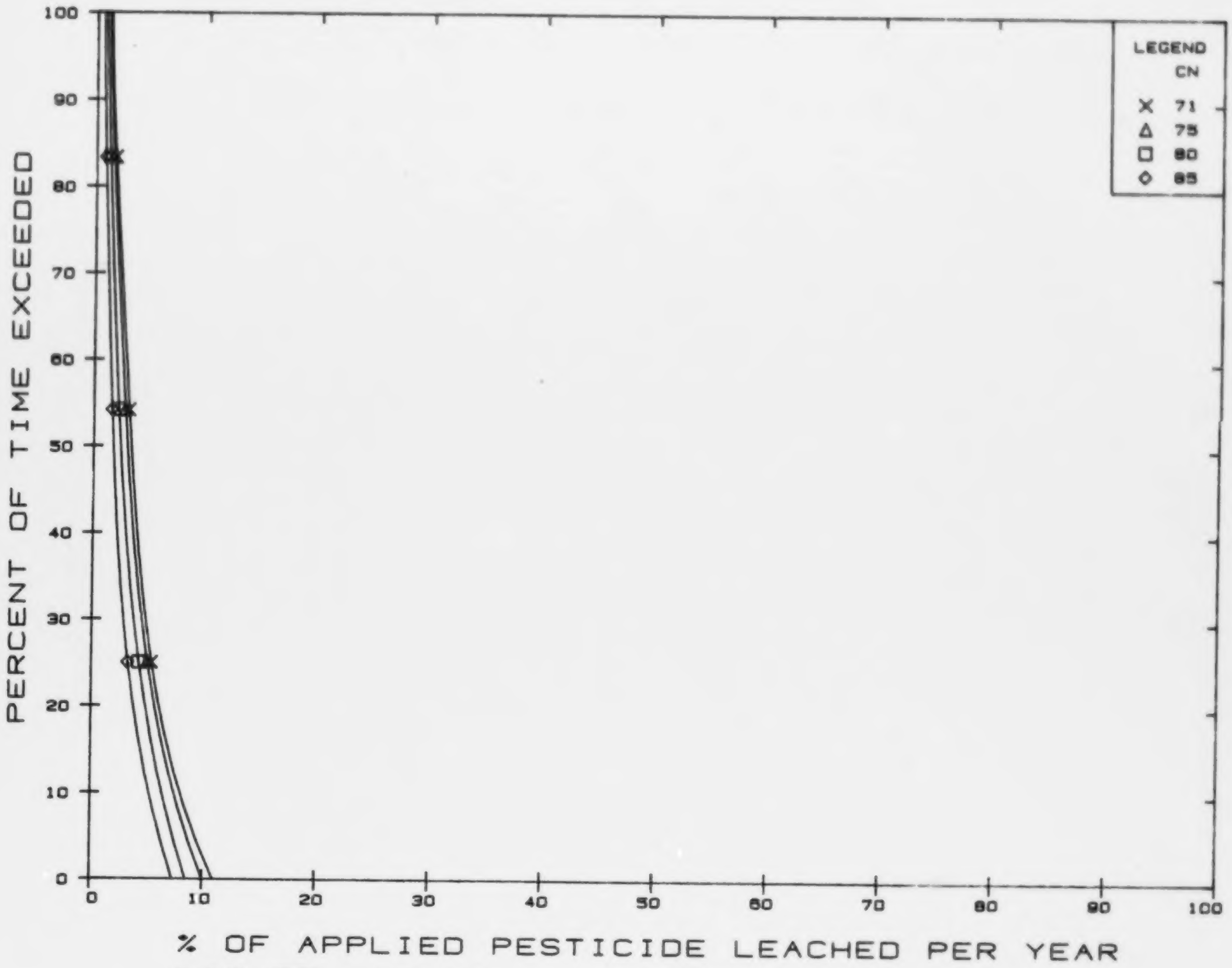


FIGURE A15-18 R=50. KS=.001

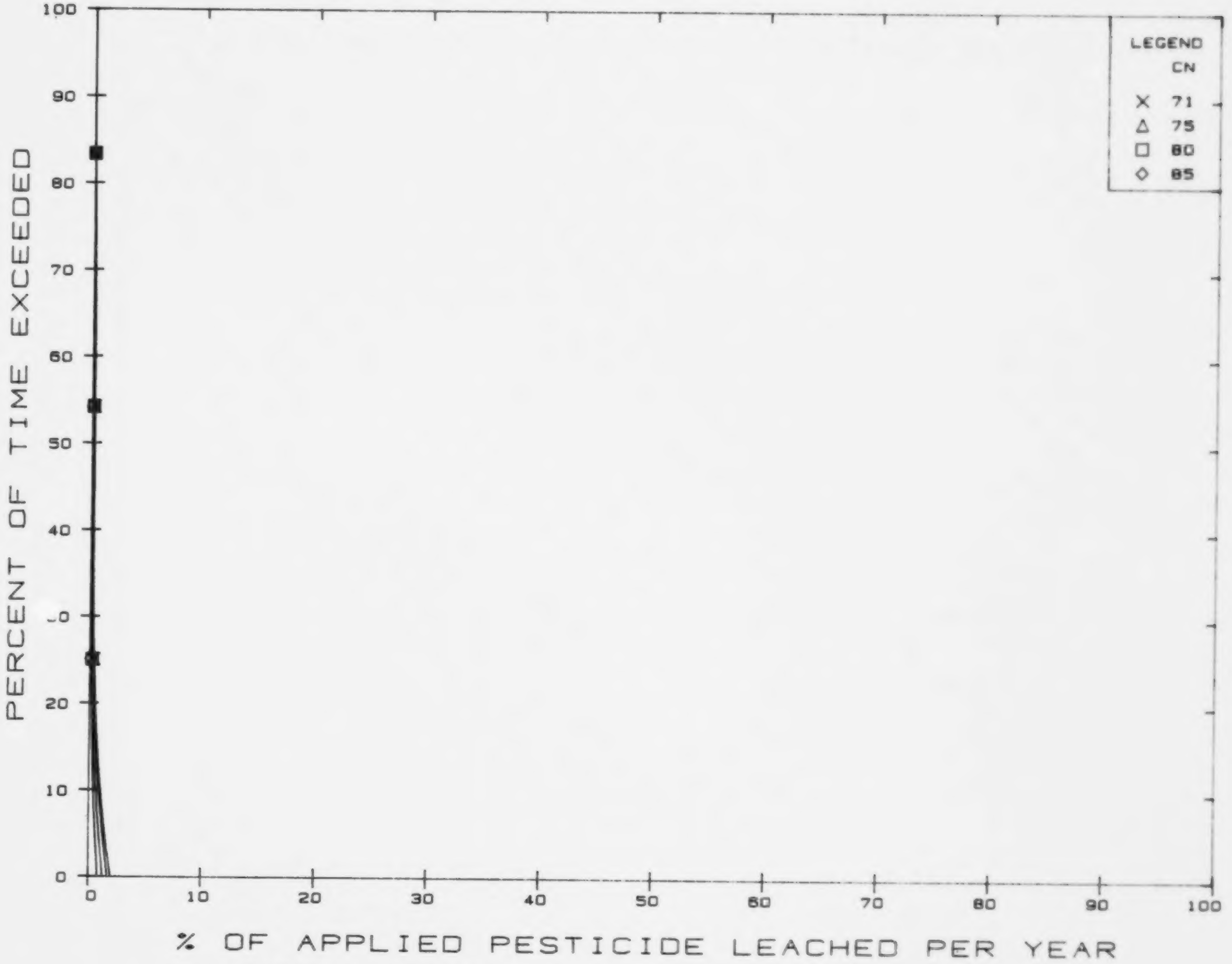


FIGURE A15-19 R=50. KS=.005

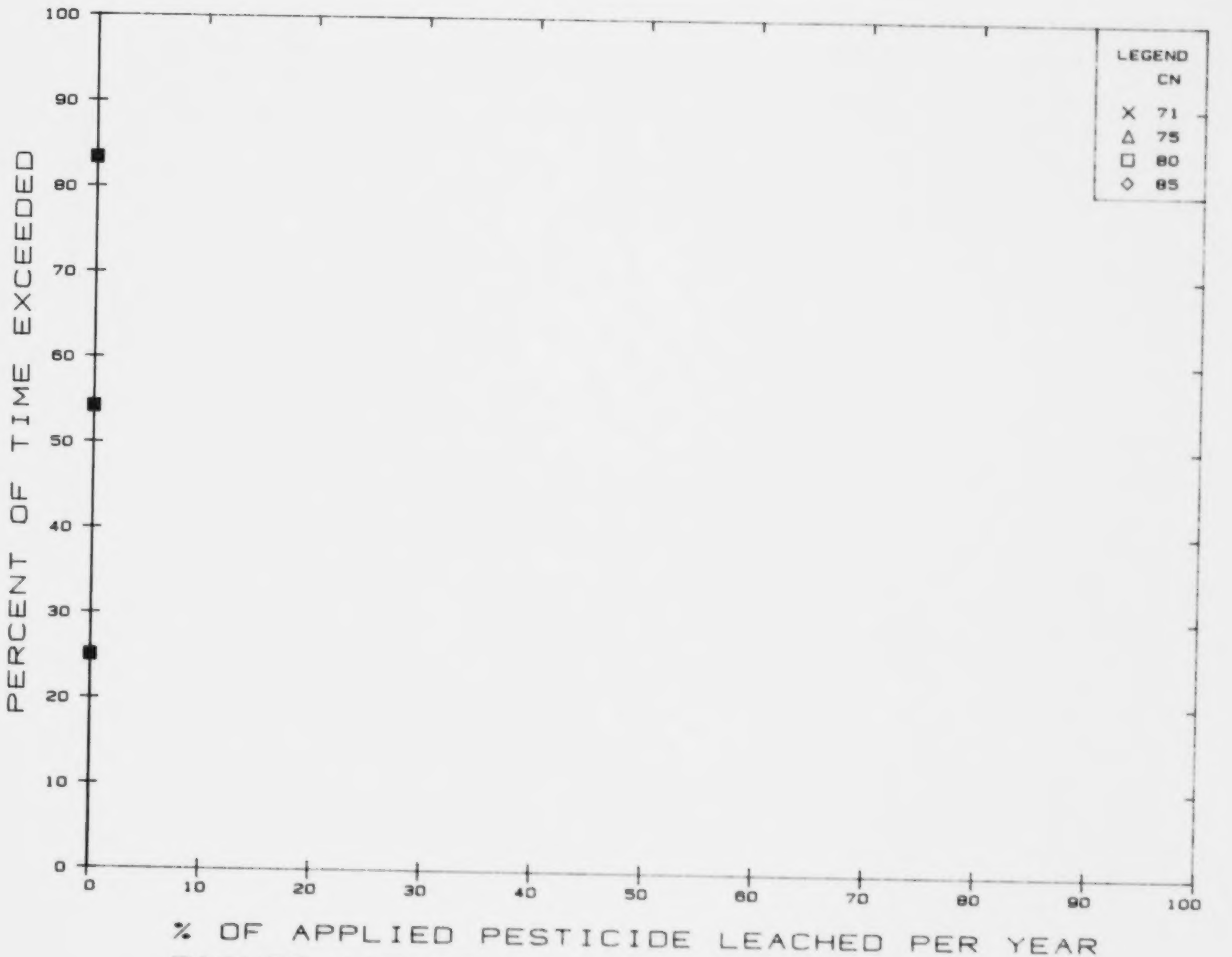


FIGURE A15-20 R=50. KS=.010

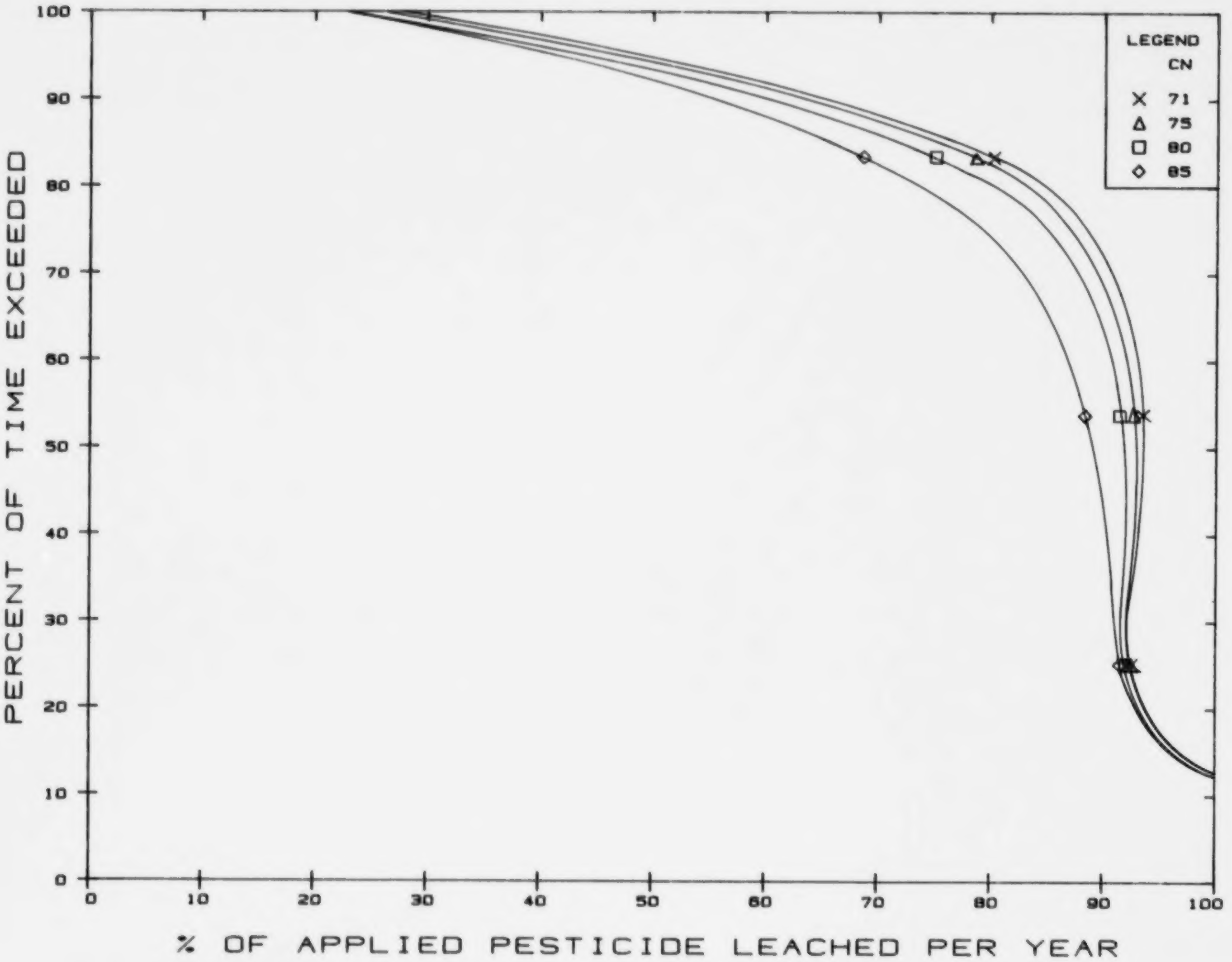


FIGURE A16-1 R=1. KS=.001

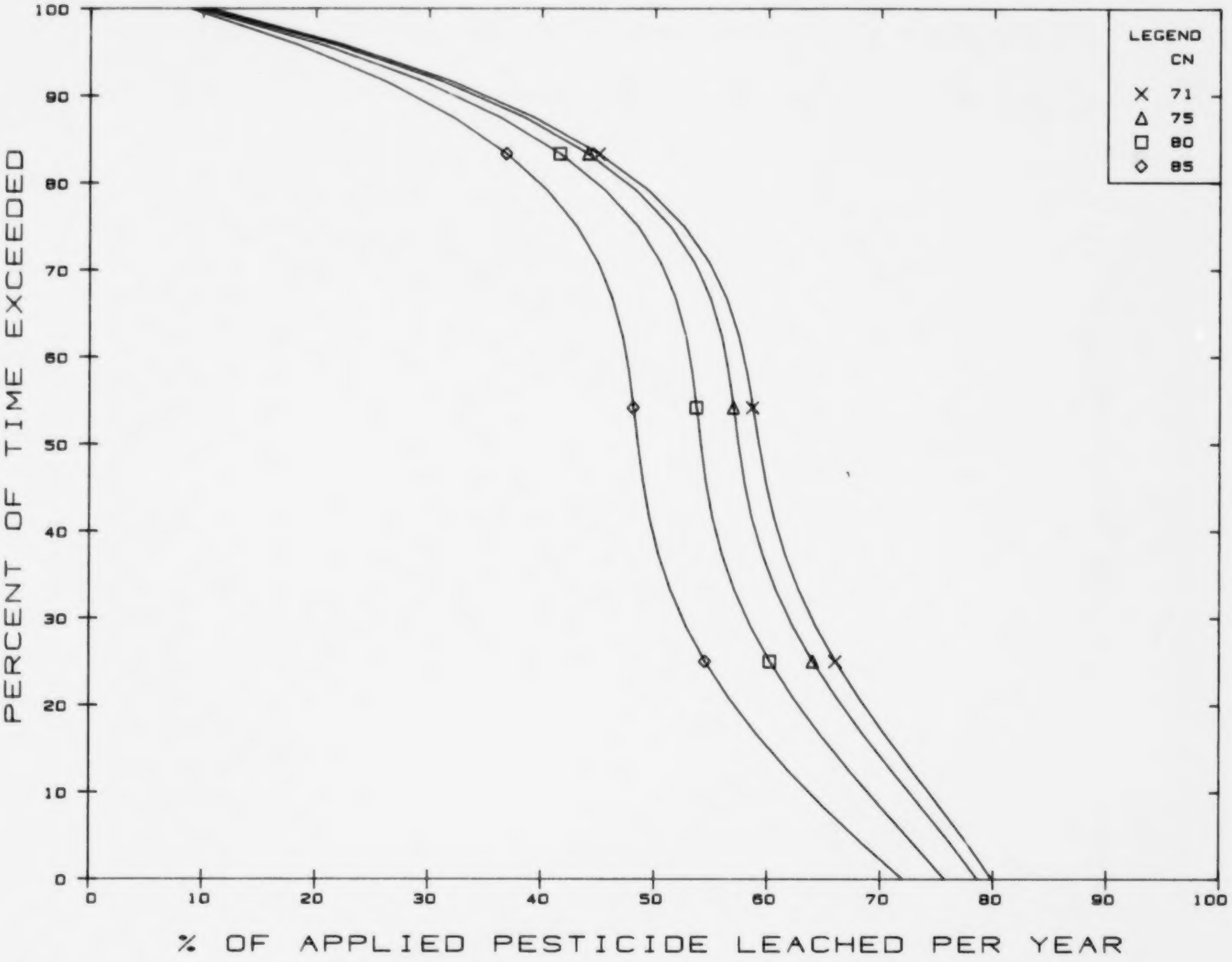


FIGURE A16-2 R=1. KS=.005

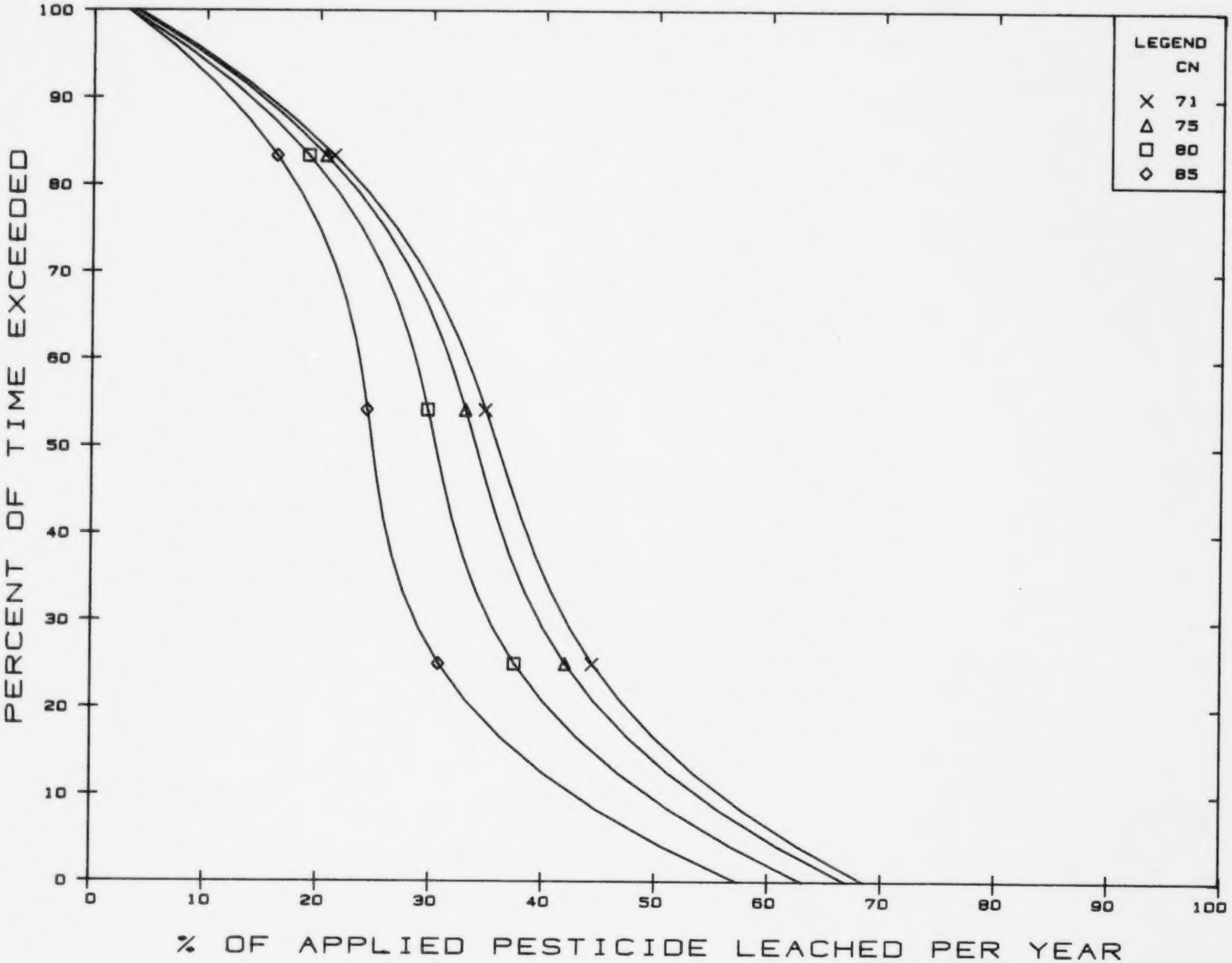


FIGURE A16-3 R=1. KS=.010

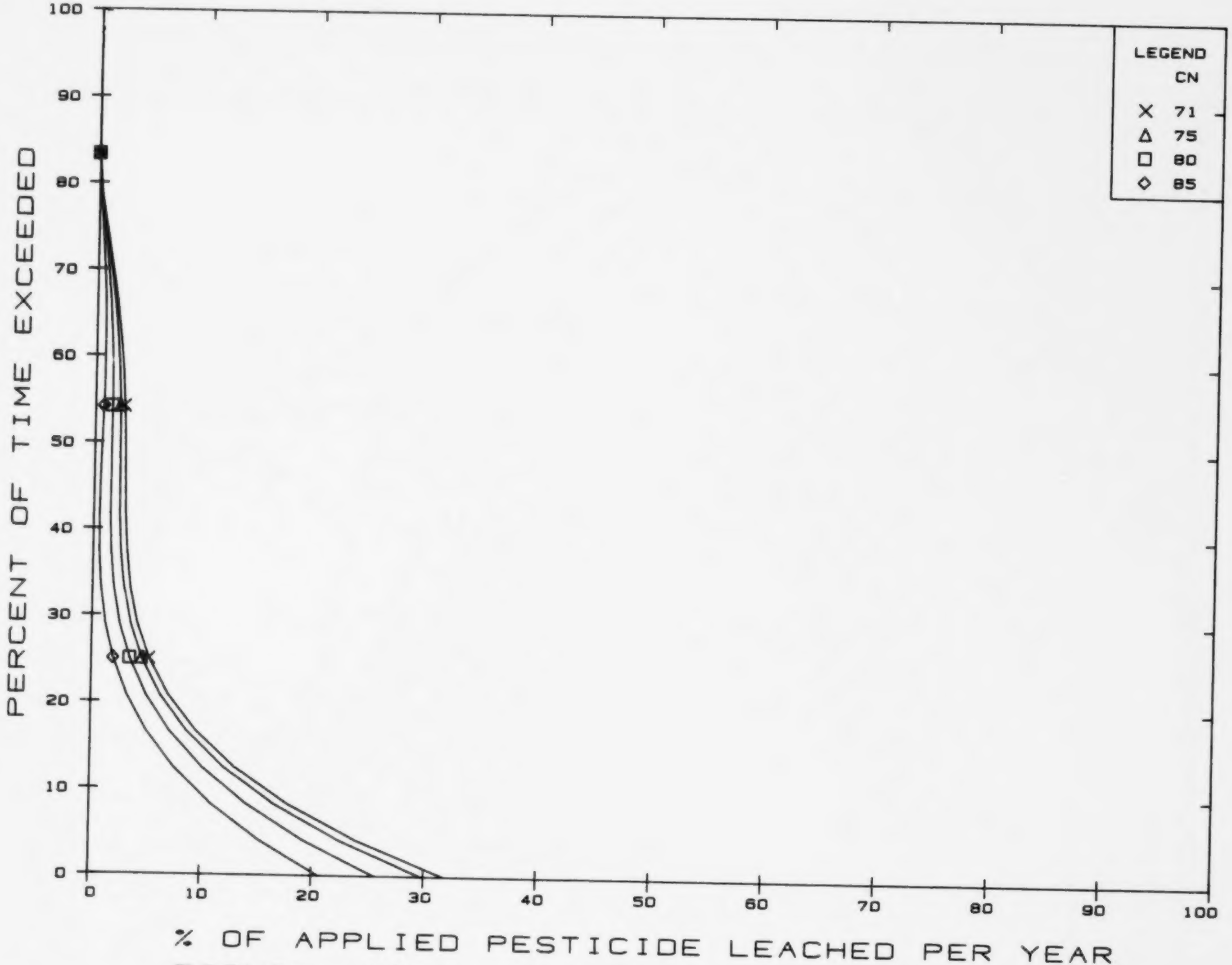


FIGURE A16-4 R=1. KS=.050

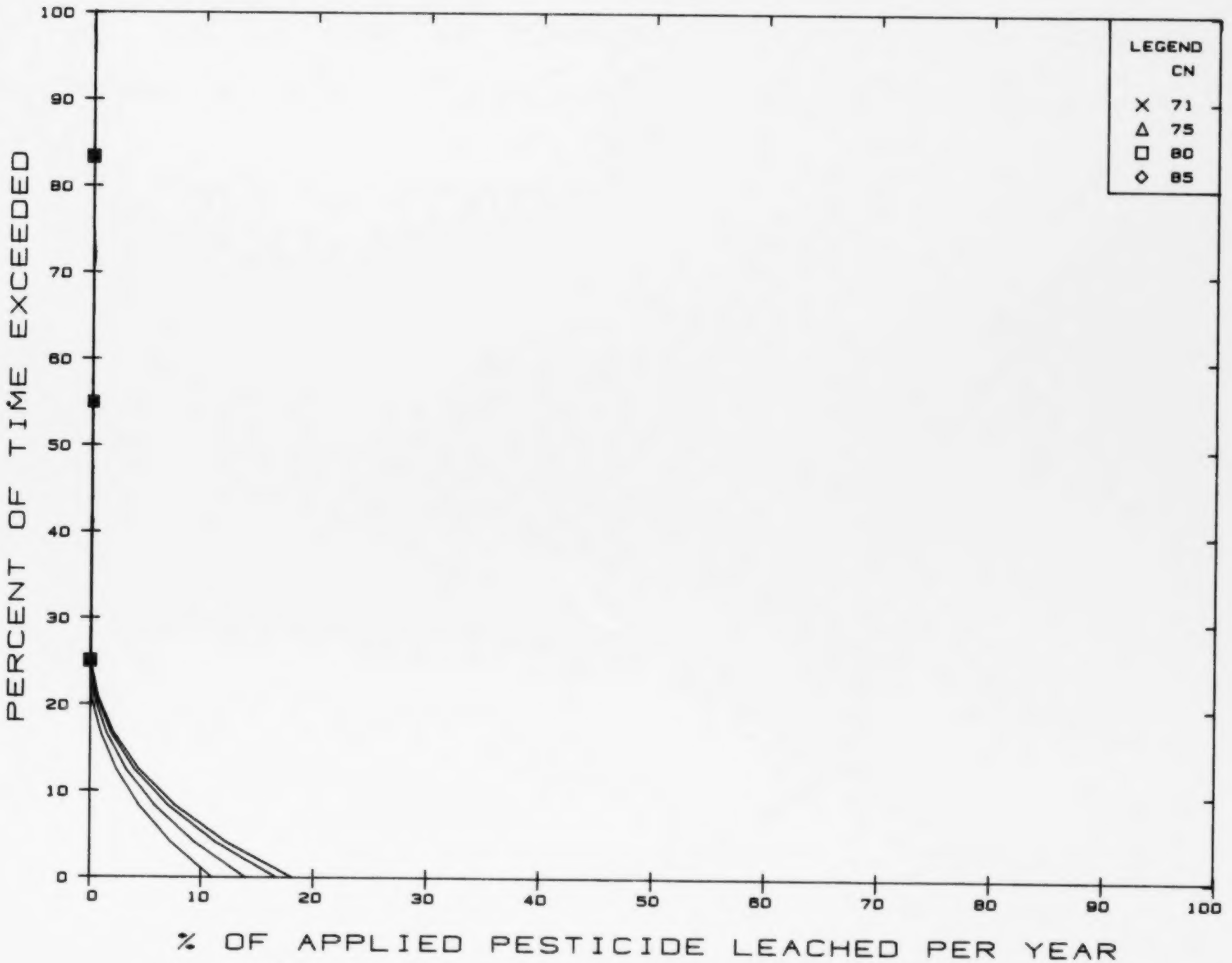


FIGURE A16-5 R=1. KS=.100

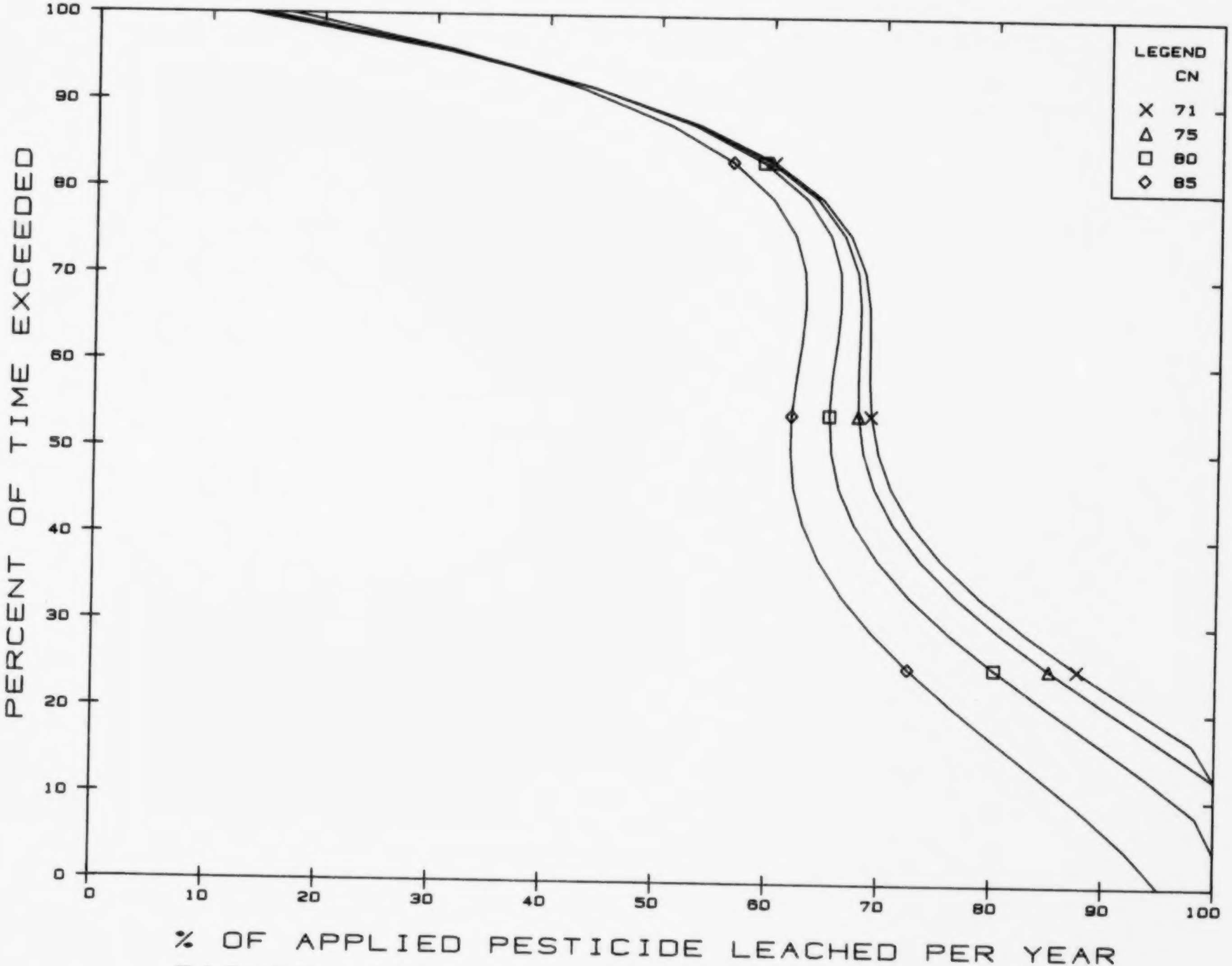


FIGURE A16-6 R=3. KS=.001

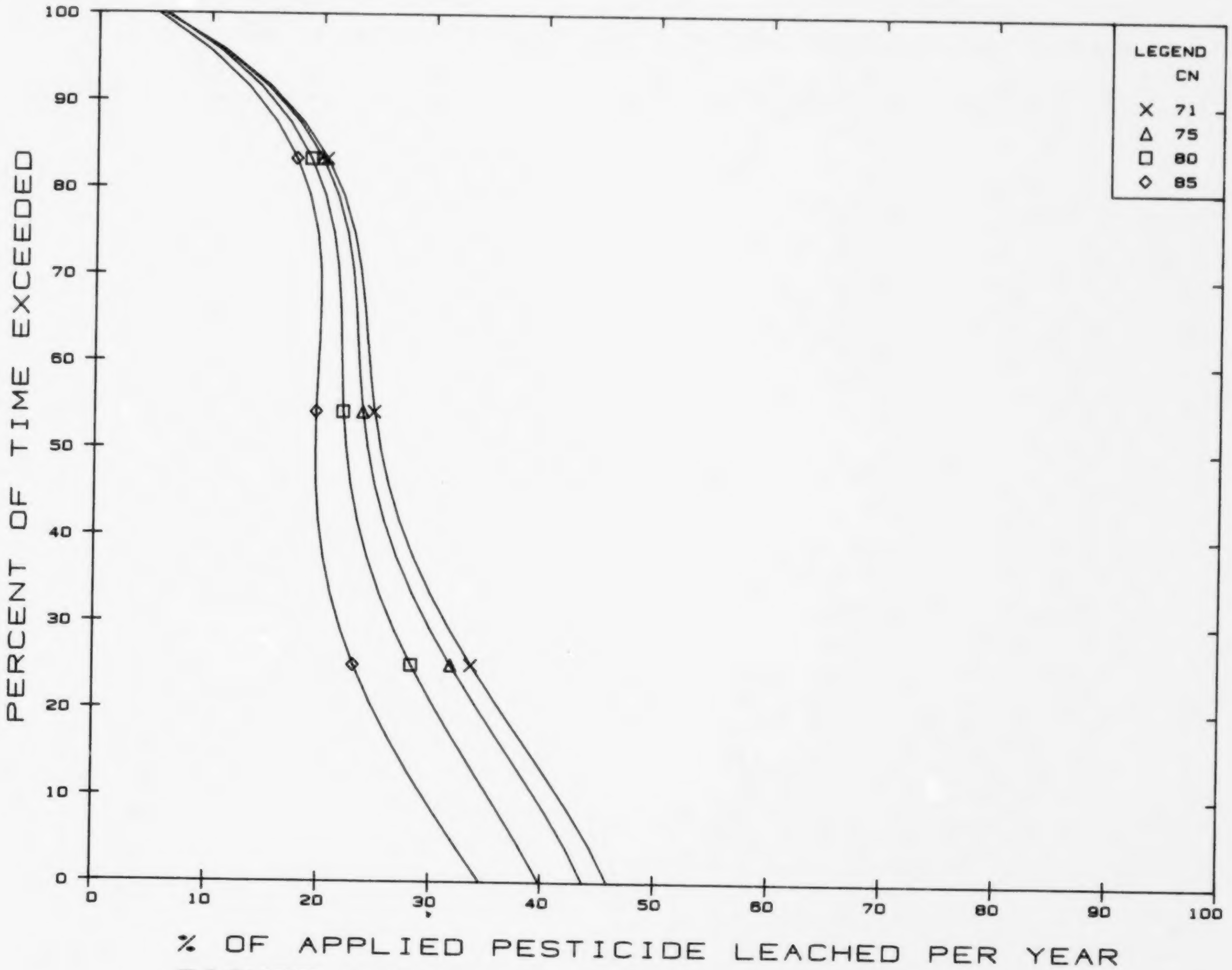


FIGURE A16-7 R=3. KS=.005

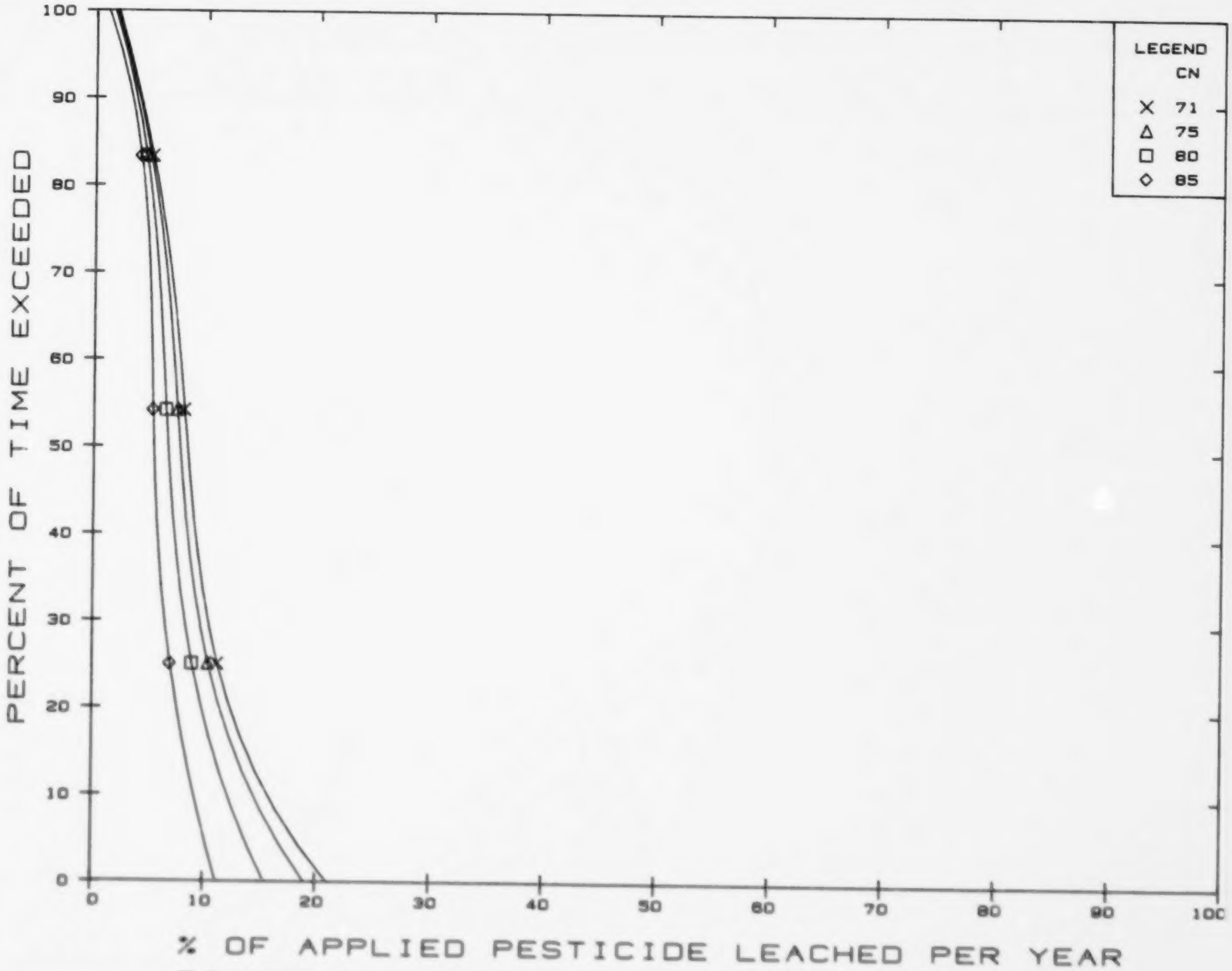


FIGURE A16-8 R=3. KS=.010

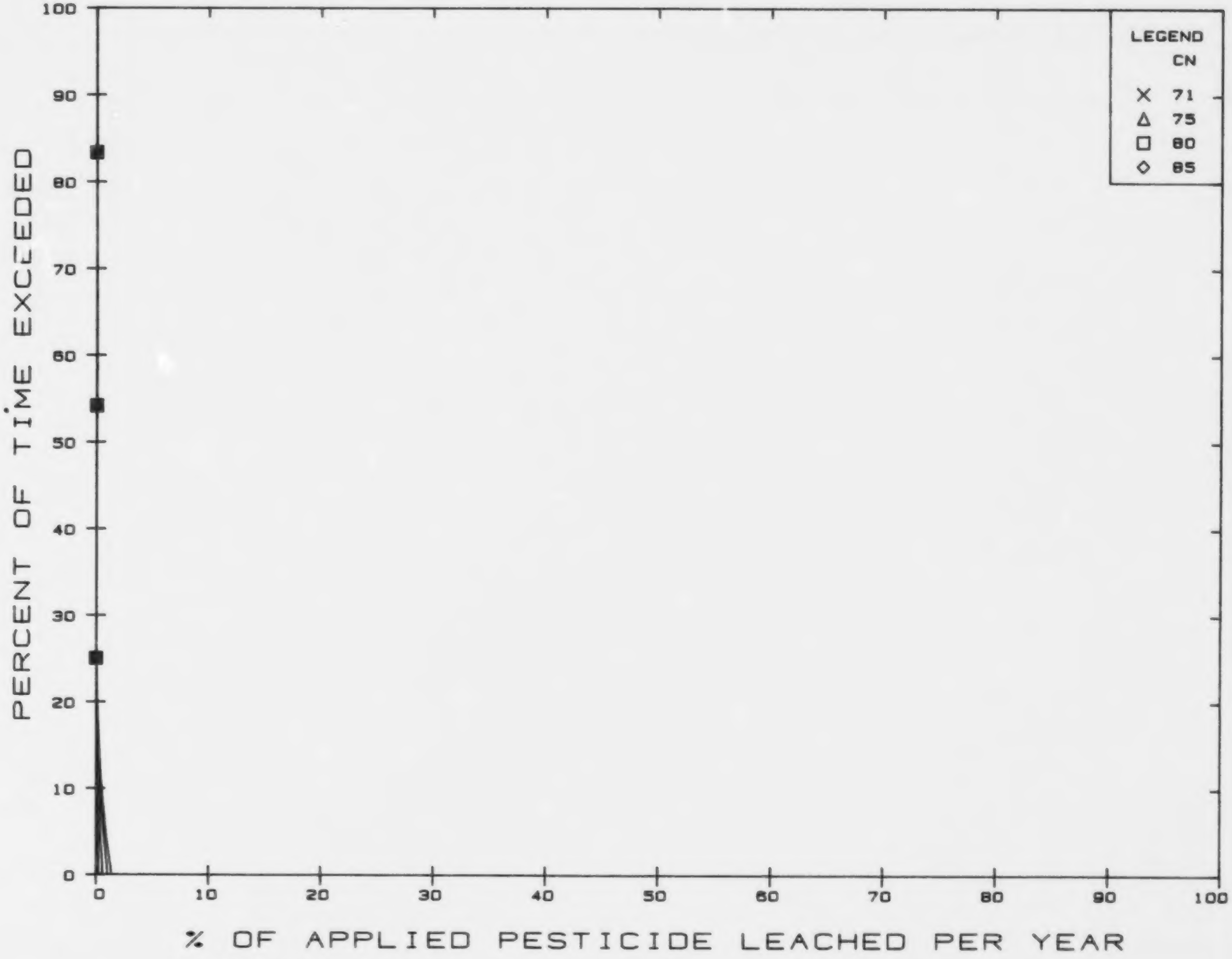


FIGURE A16-9 R=3. KS=.050

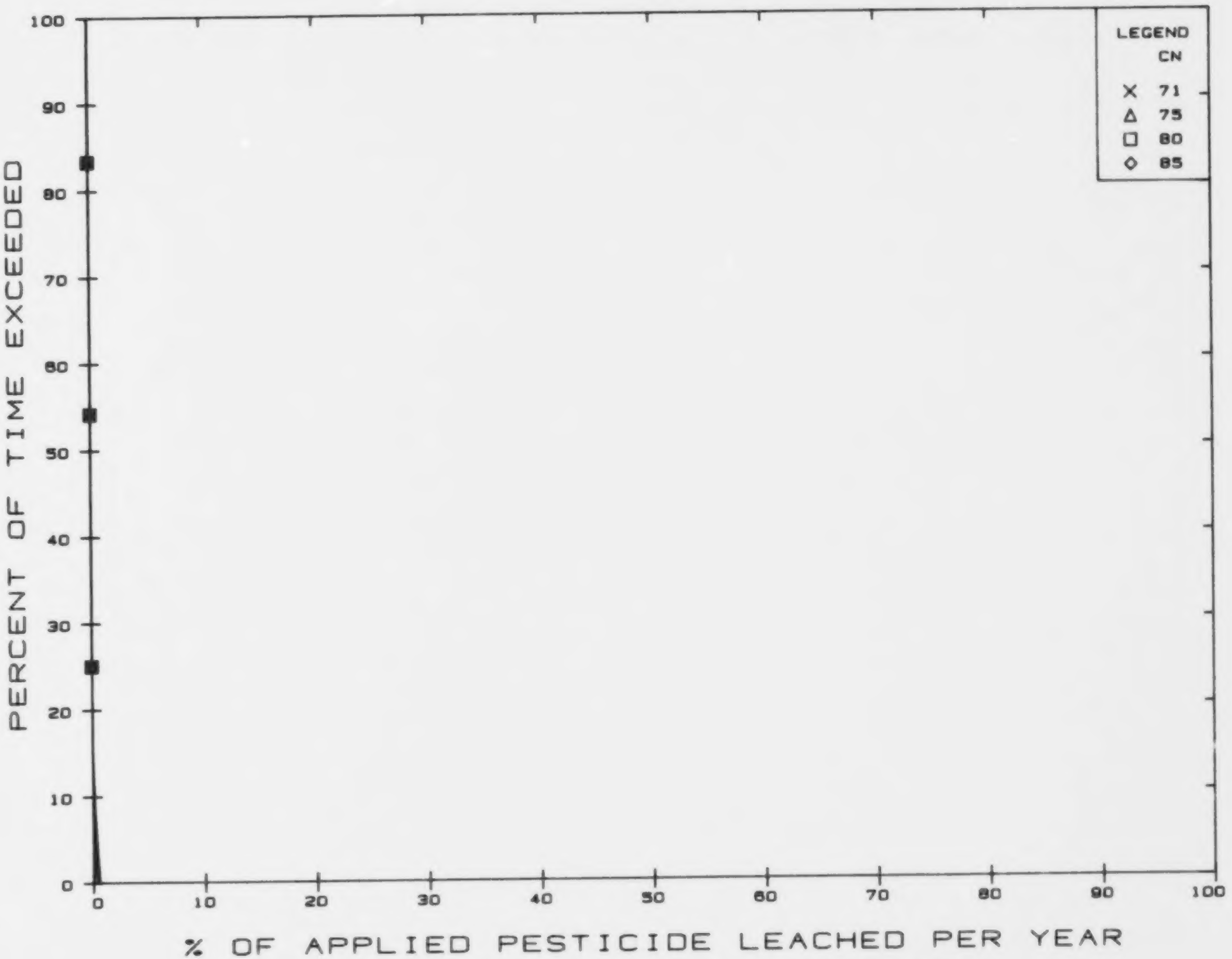


FIGURE A16-10 R=3. KS=.100

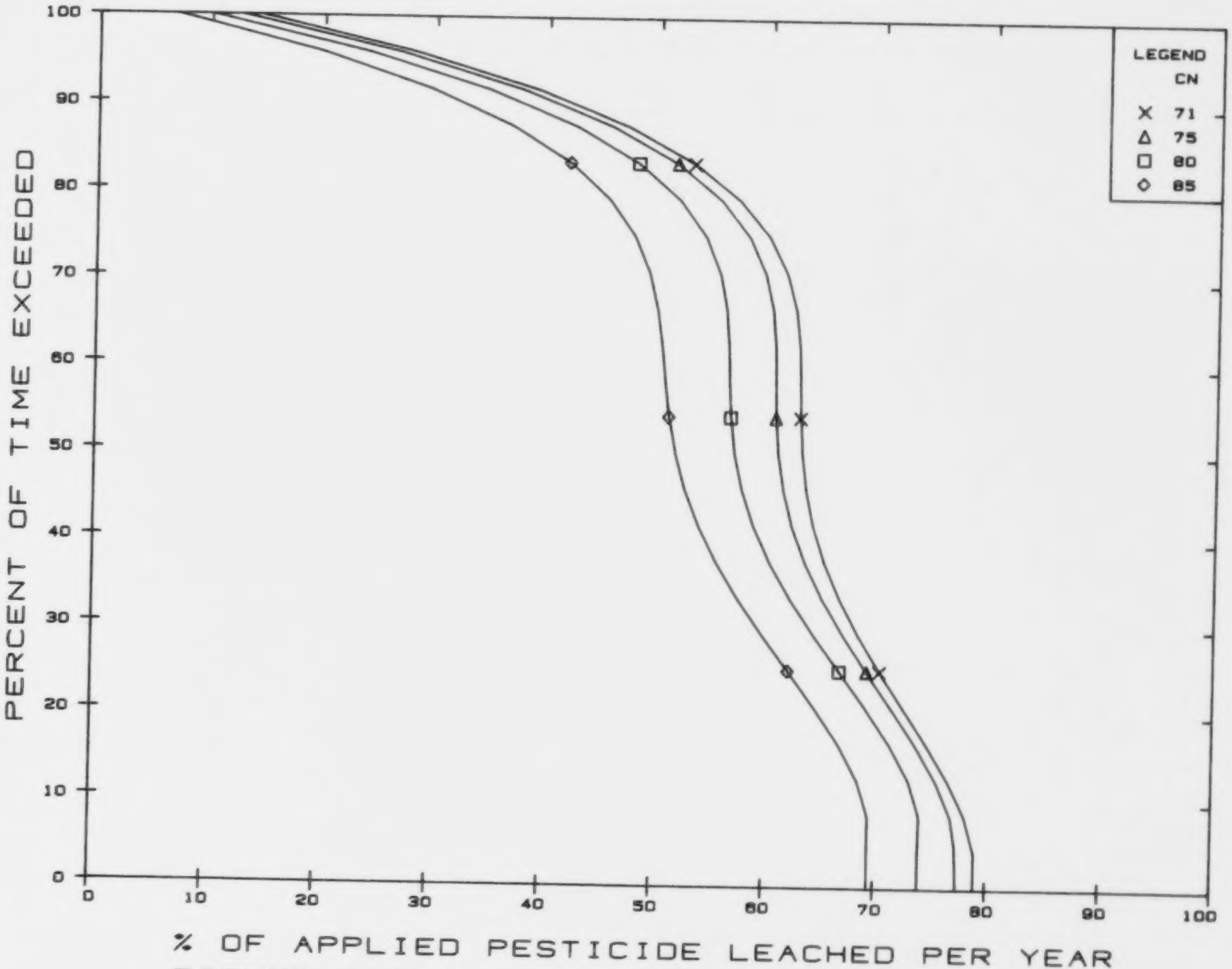


FIGURE A16-11 R=5. KS=.001

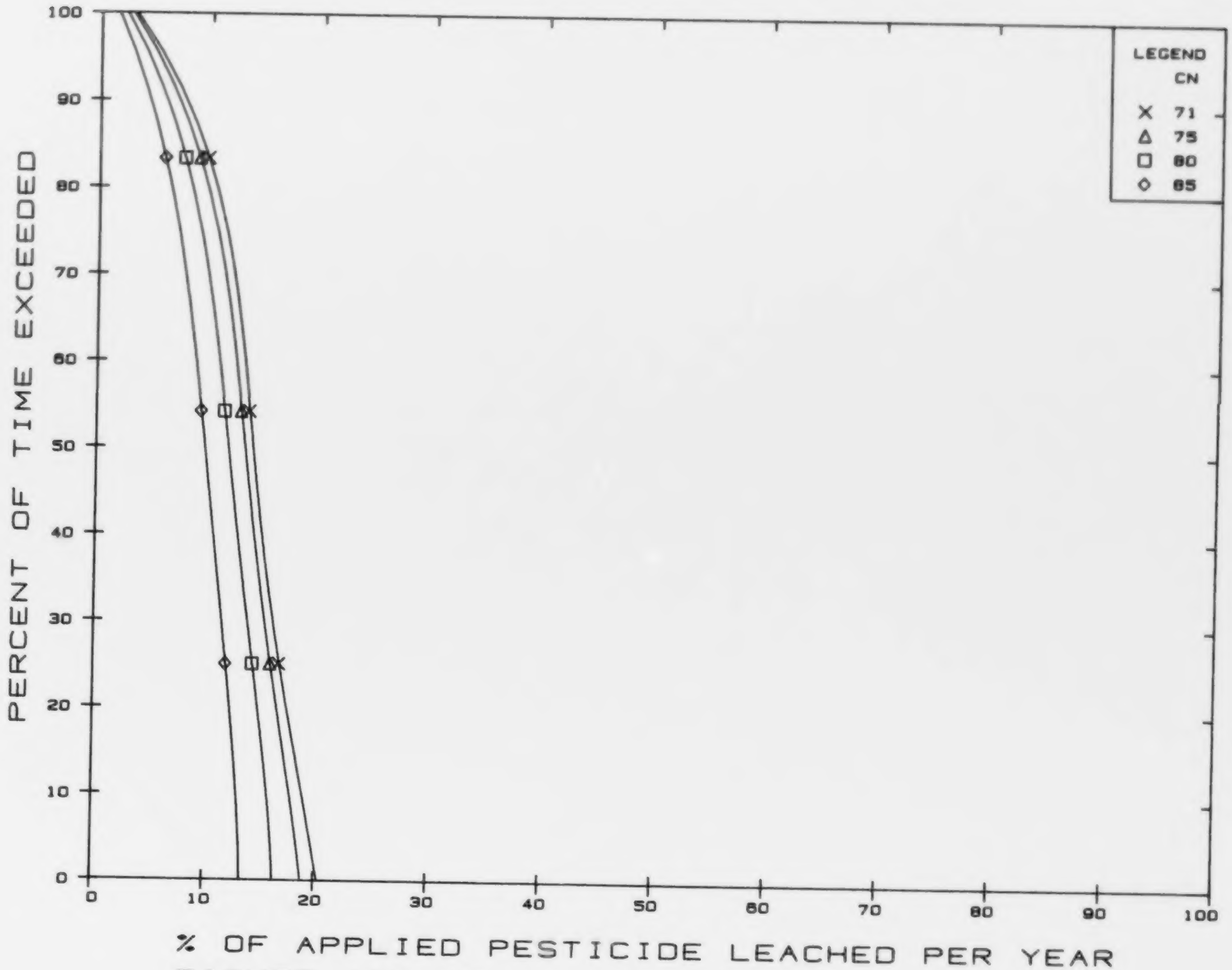
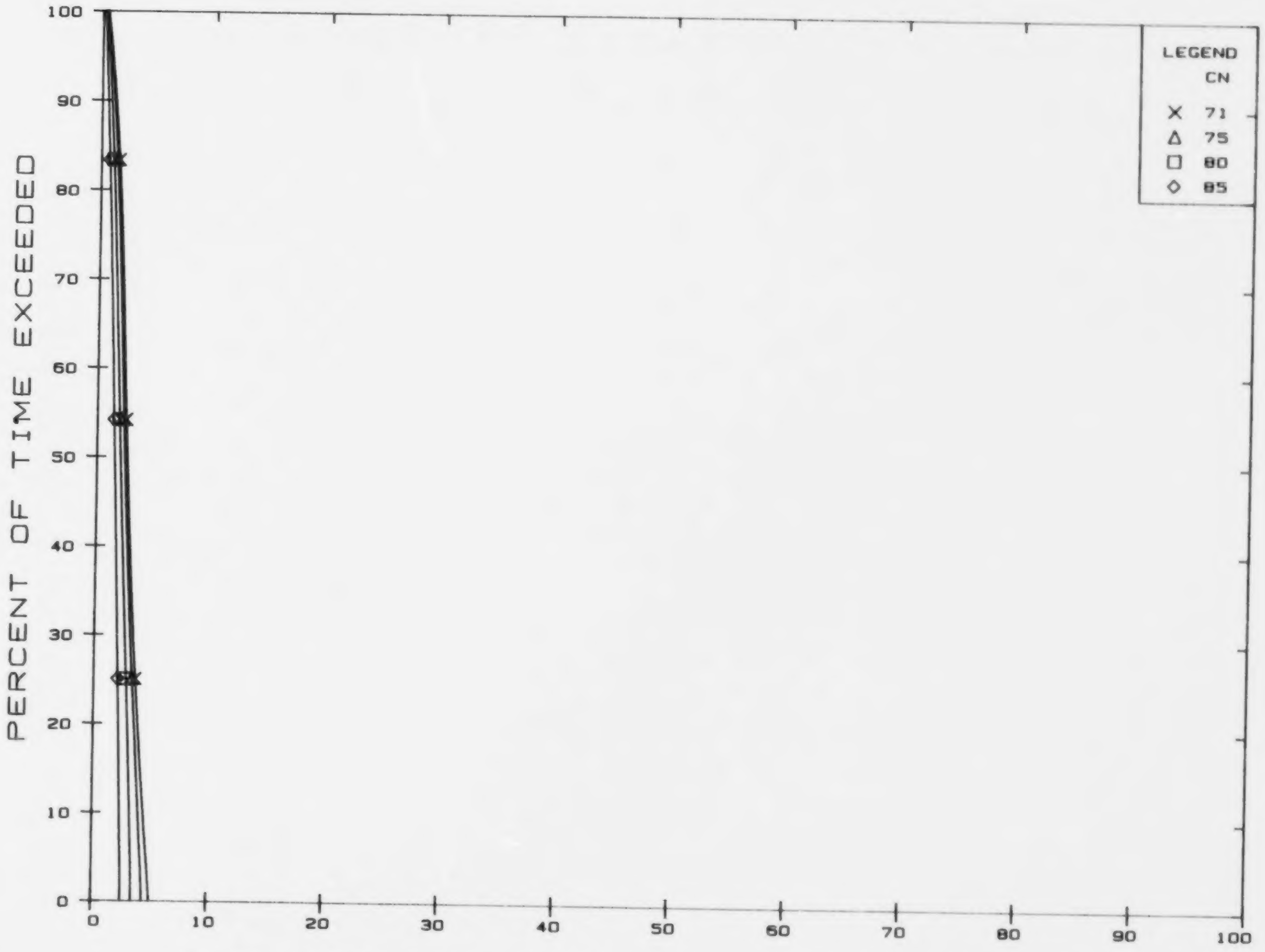


FIGURE A16-12 R=5. KS=.005



% OF APPLIED PESTICIDE LEACHED PER YEAR
FIGURE A16-13 R=5. KS=.010

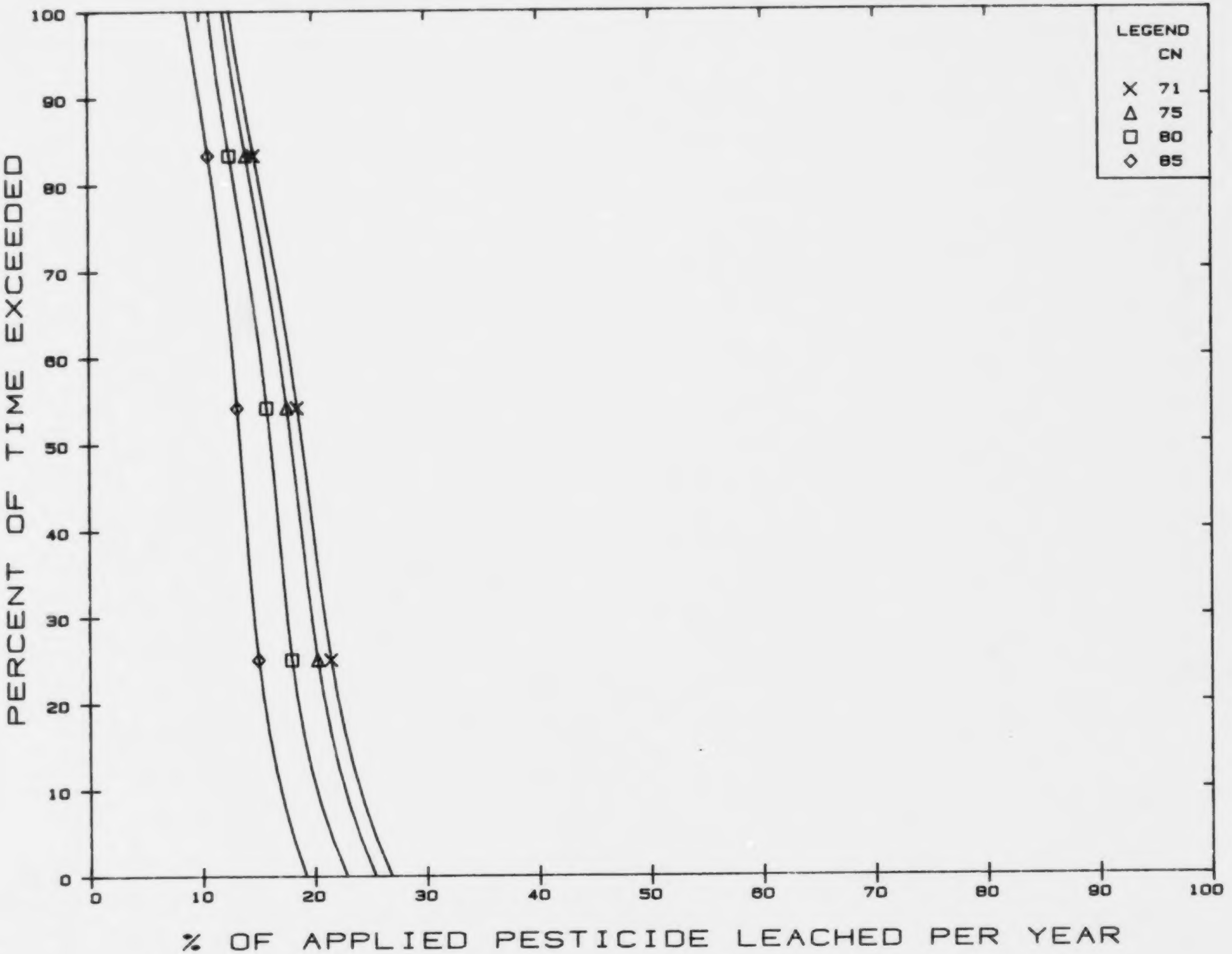


FIGURE A16-15 R=20. KS=.001

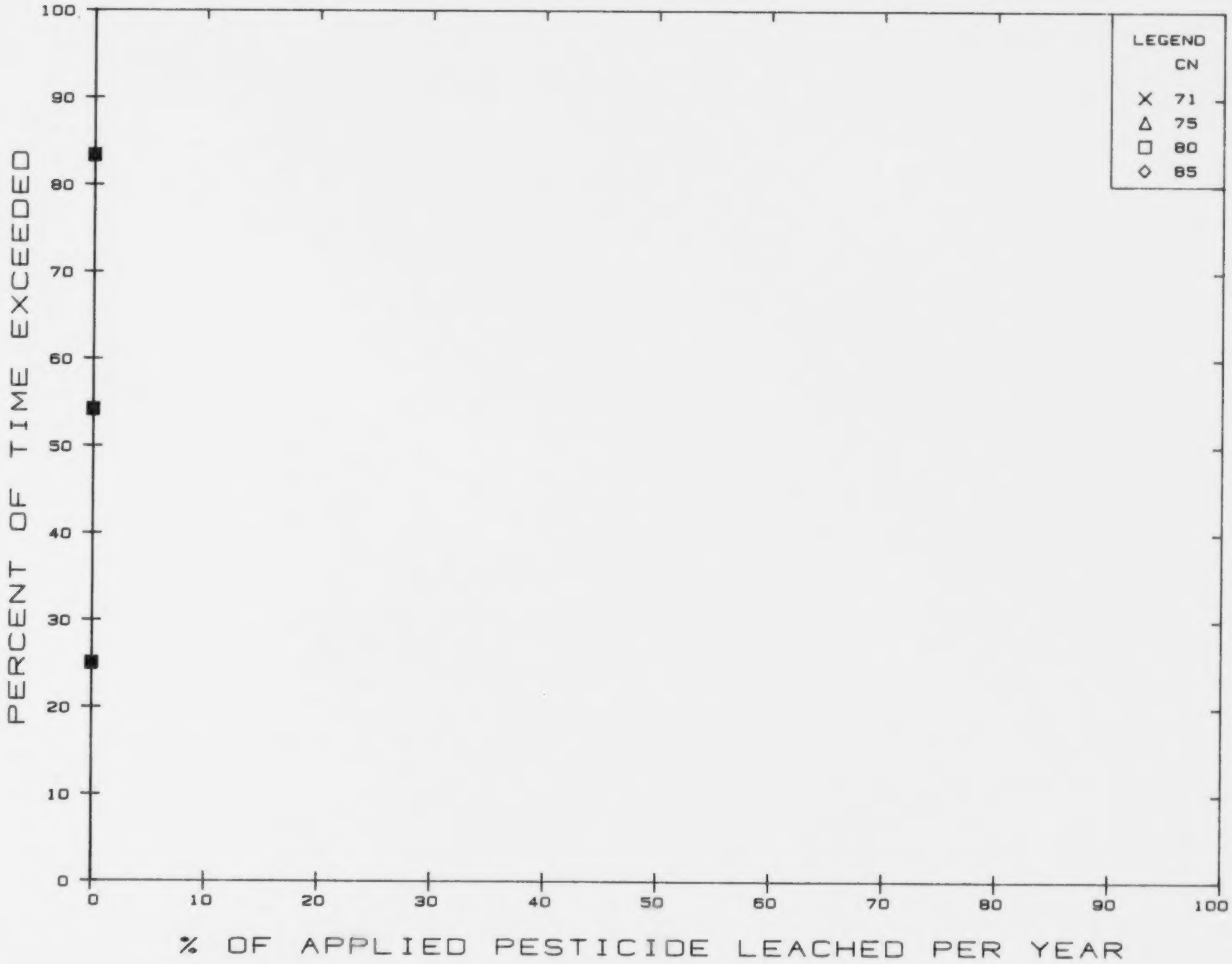


FIGURE A16-14 R=5. KS=.050

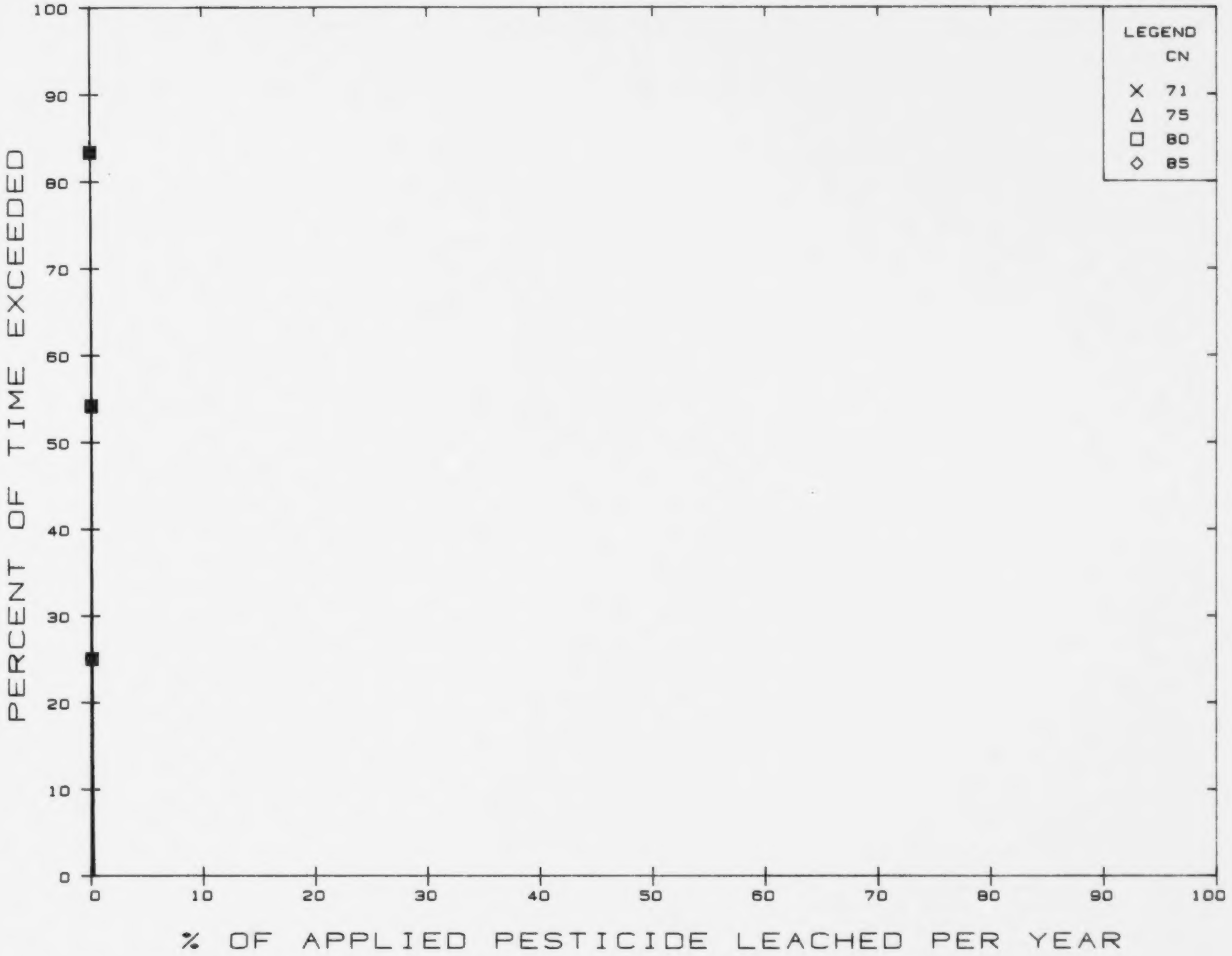


FIGURE A16-16 R=20. KS=.005

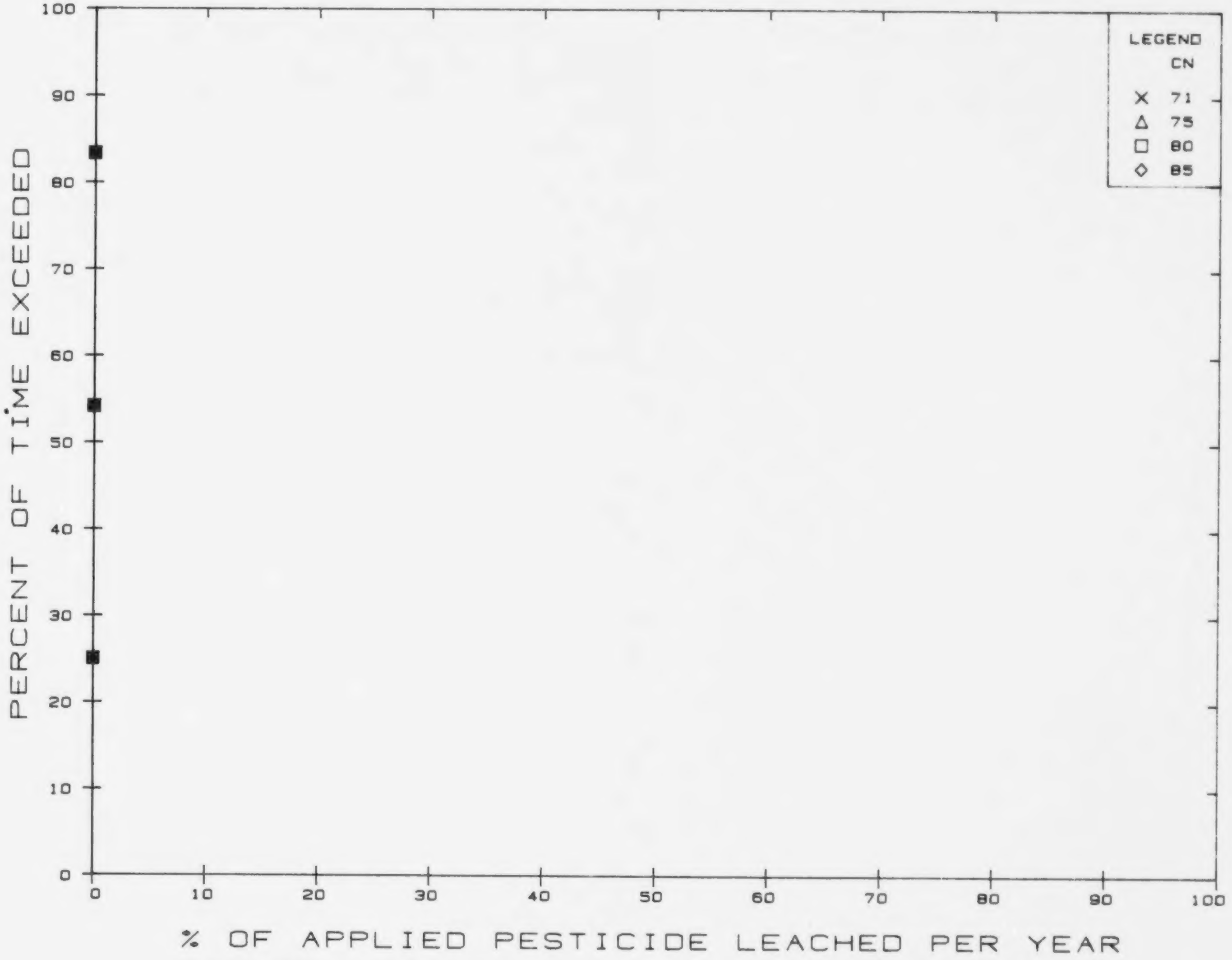


FIGURE A16-17 R=20. KS=.010

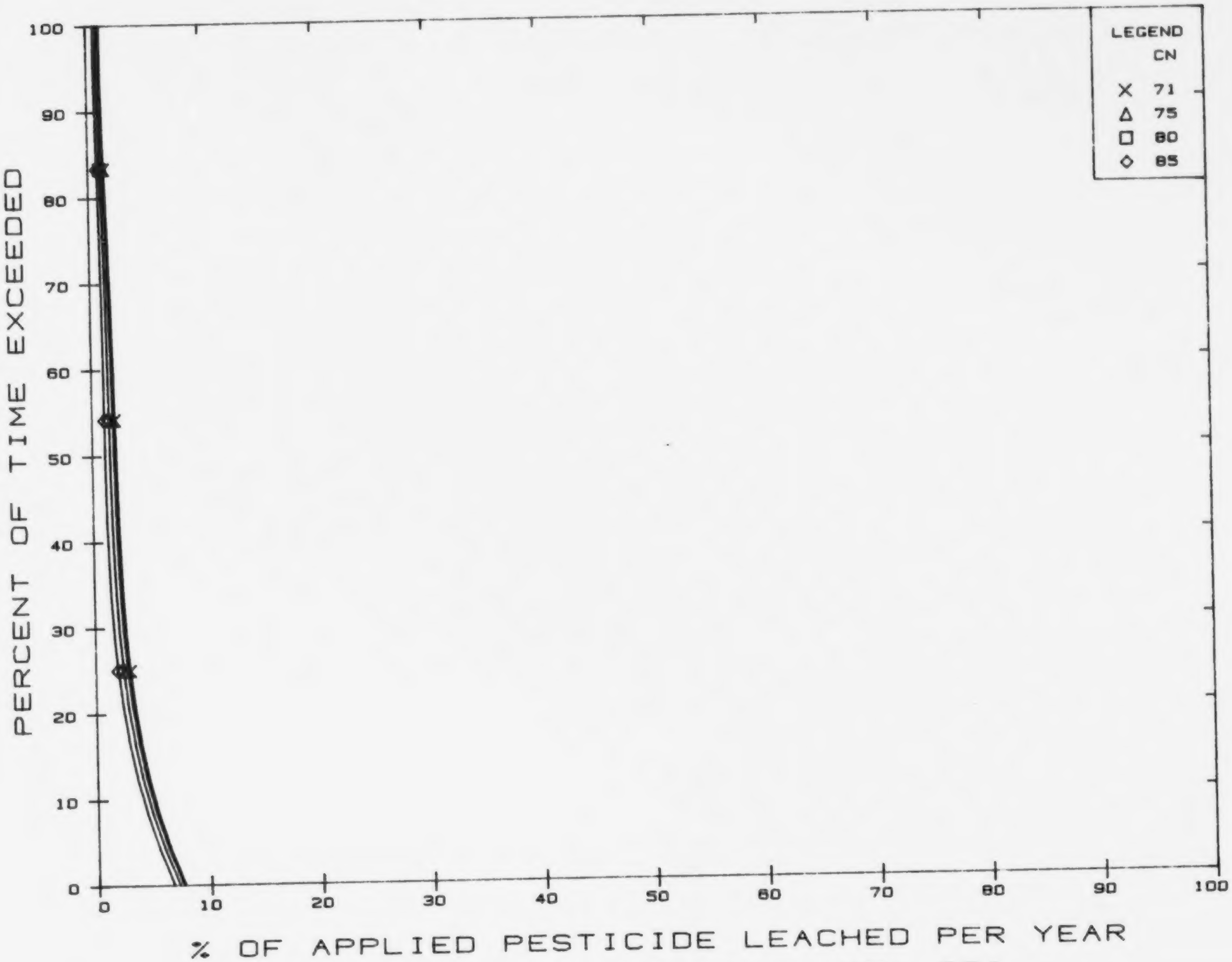


FIGURE A16-18 R=50. KS=.001

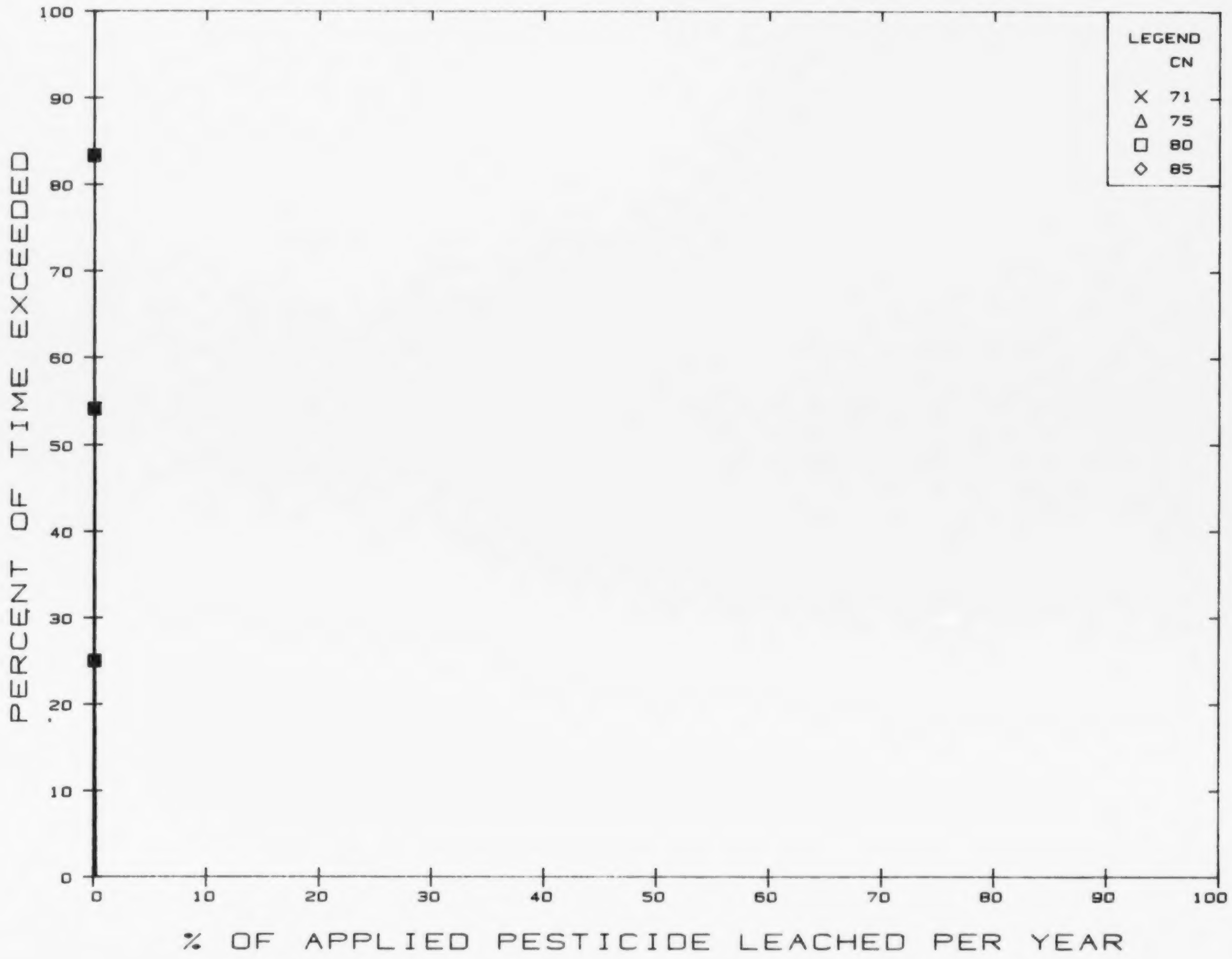


FIGURE A16-19 R=50. KS=.005

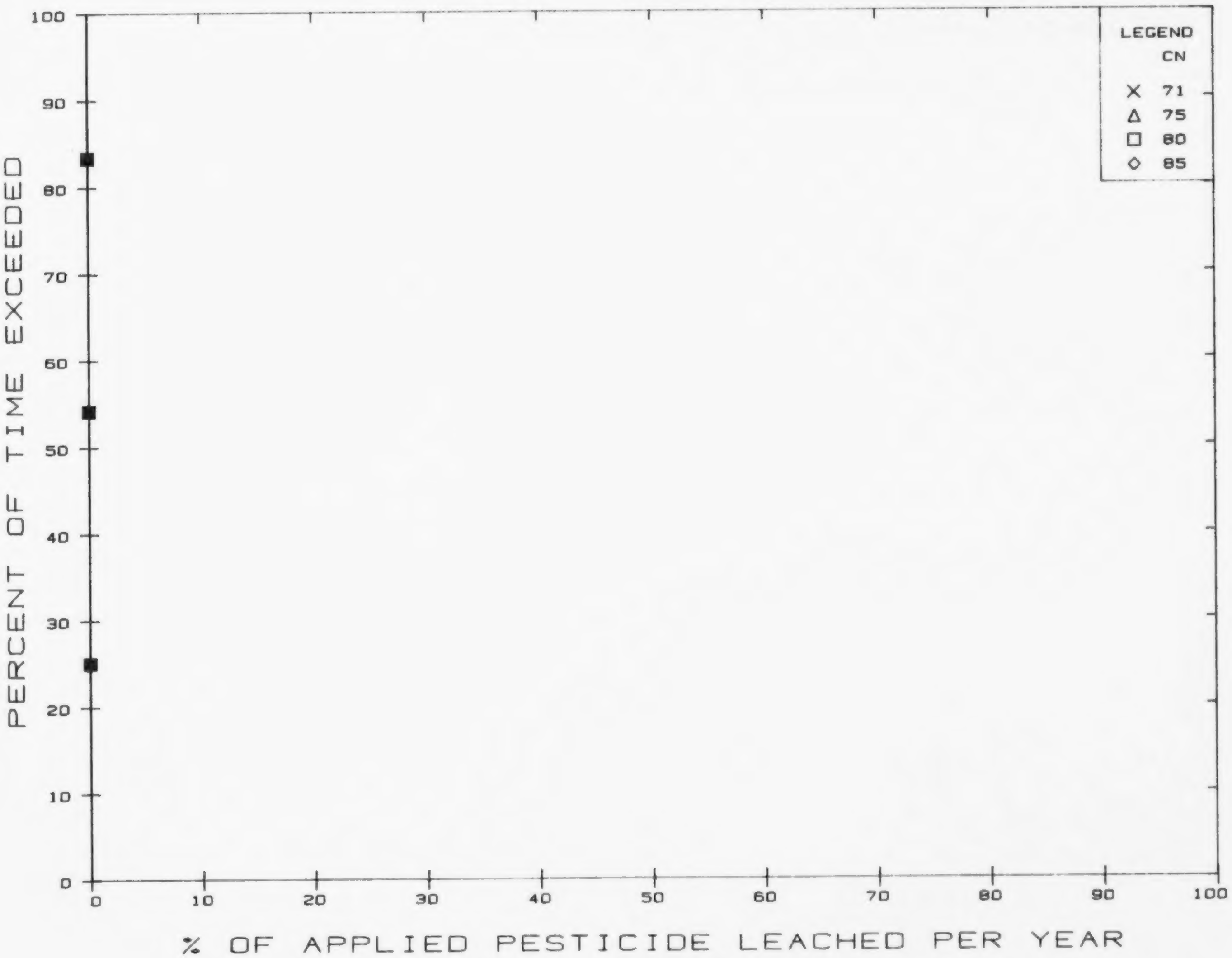


FIGURE A16-20 R=50. KS=.010

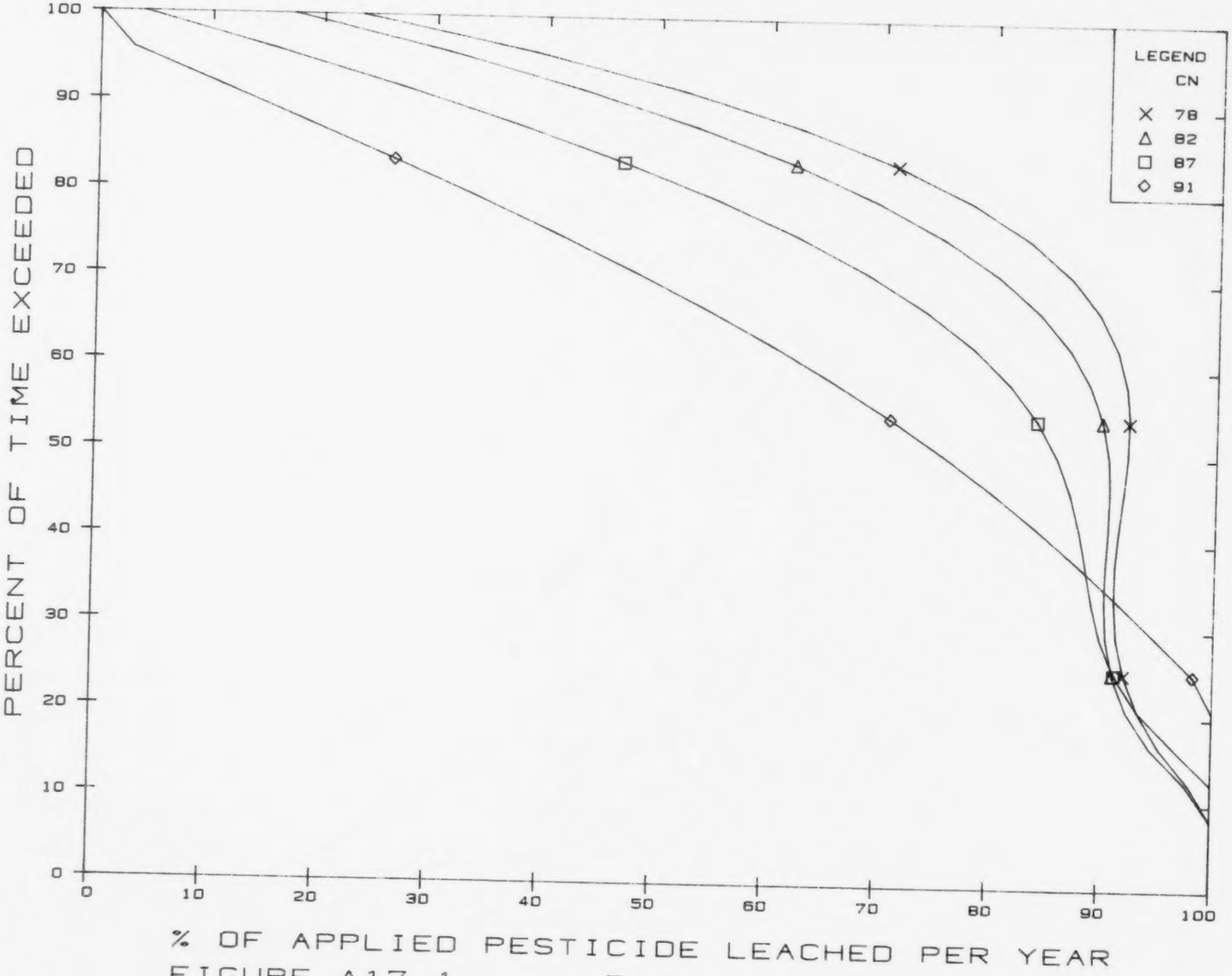


FIGURE A17-1 R=1. KS=.001

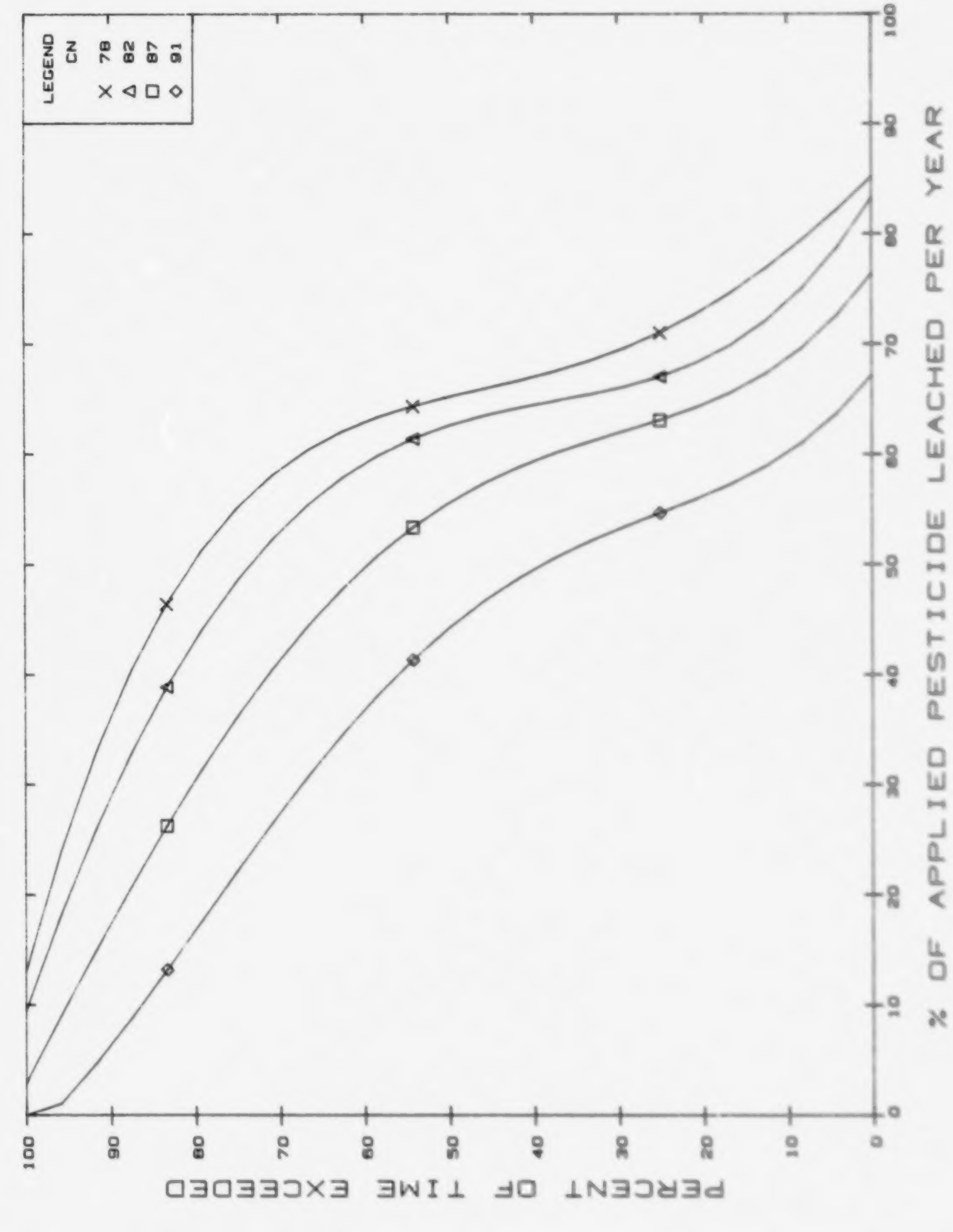


FIGURE A17-2 R=1. KS=.005

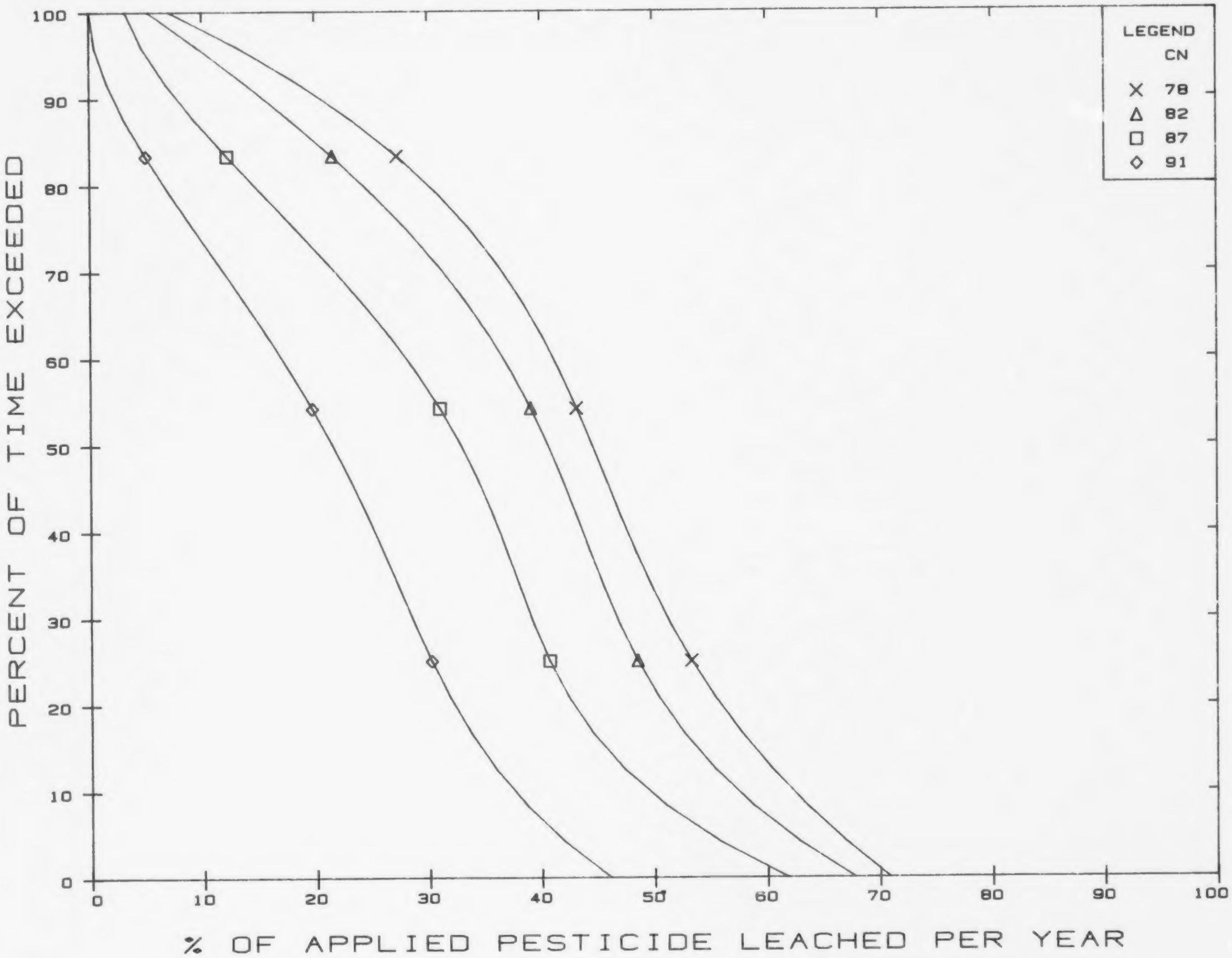


FIGURE A17-3 R=1. KS=.010

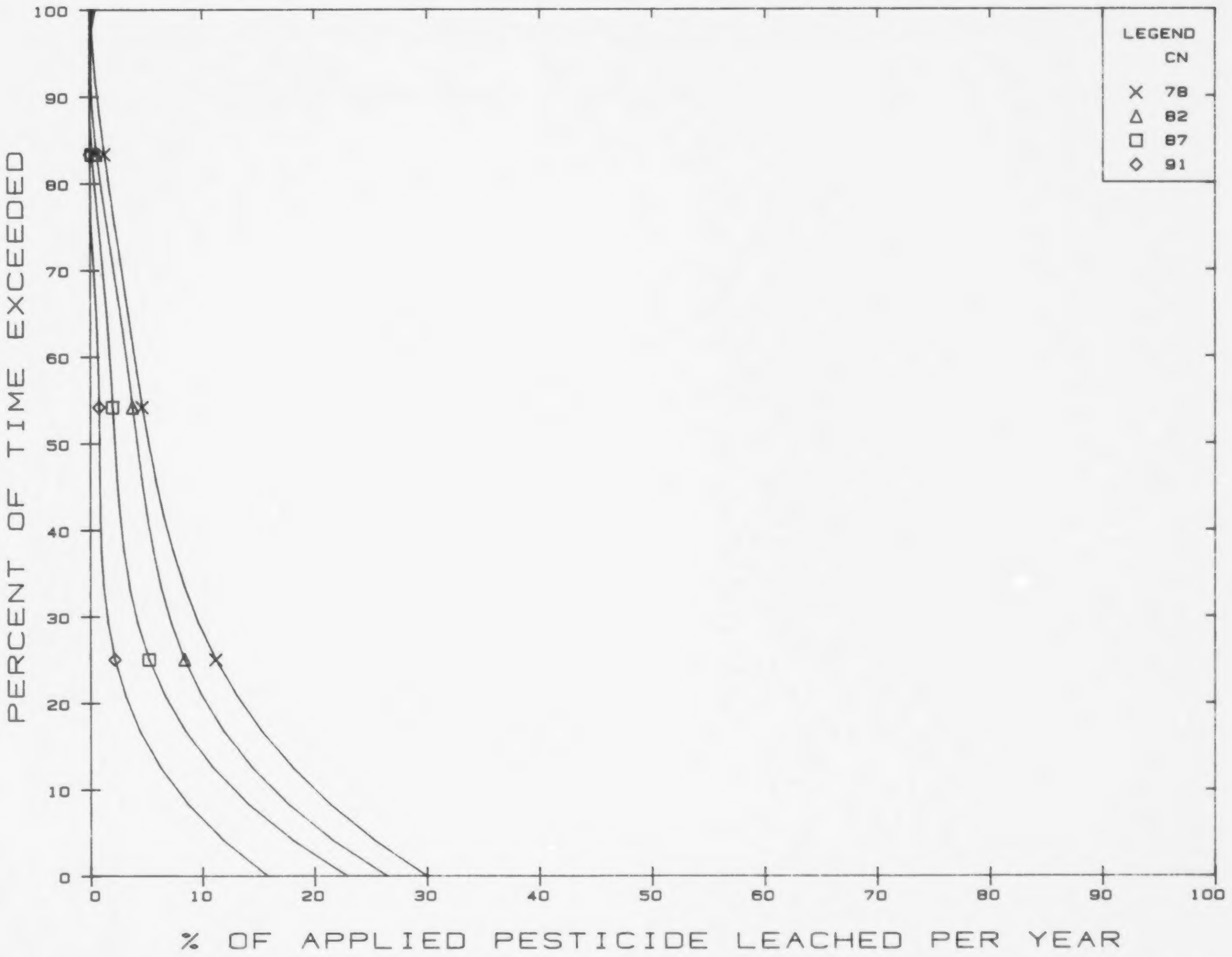


FIGURE A17-4 R=1. KS=.050

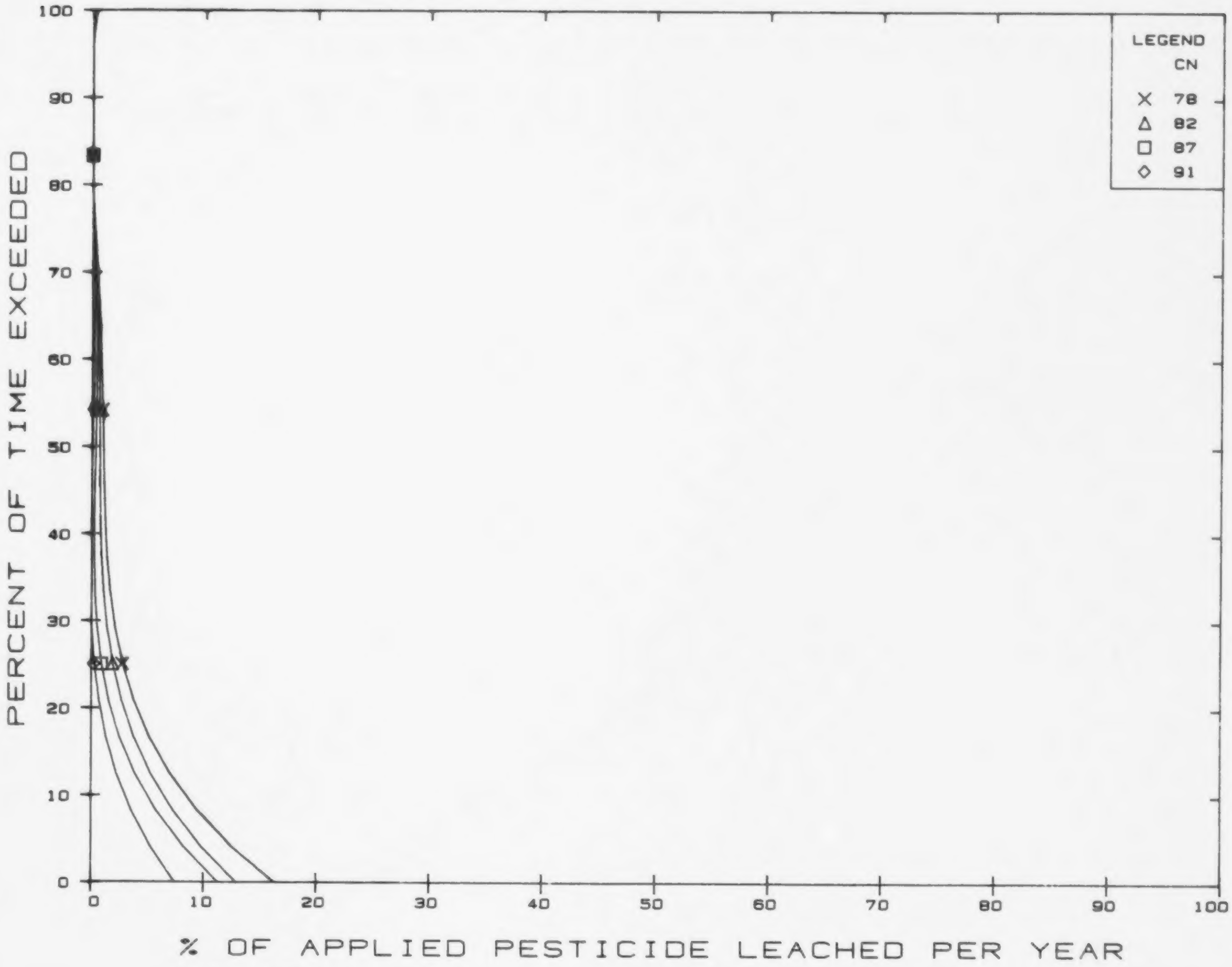


FIGURE A17-5 R=1. KS=.100

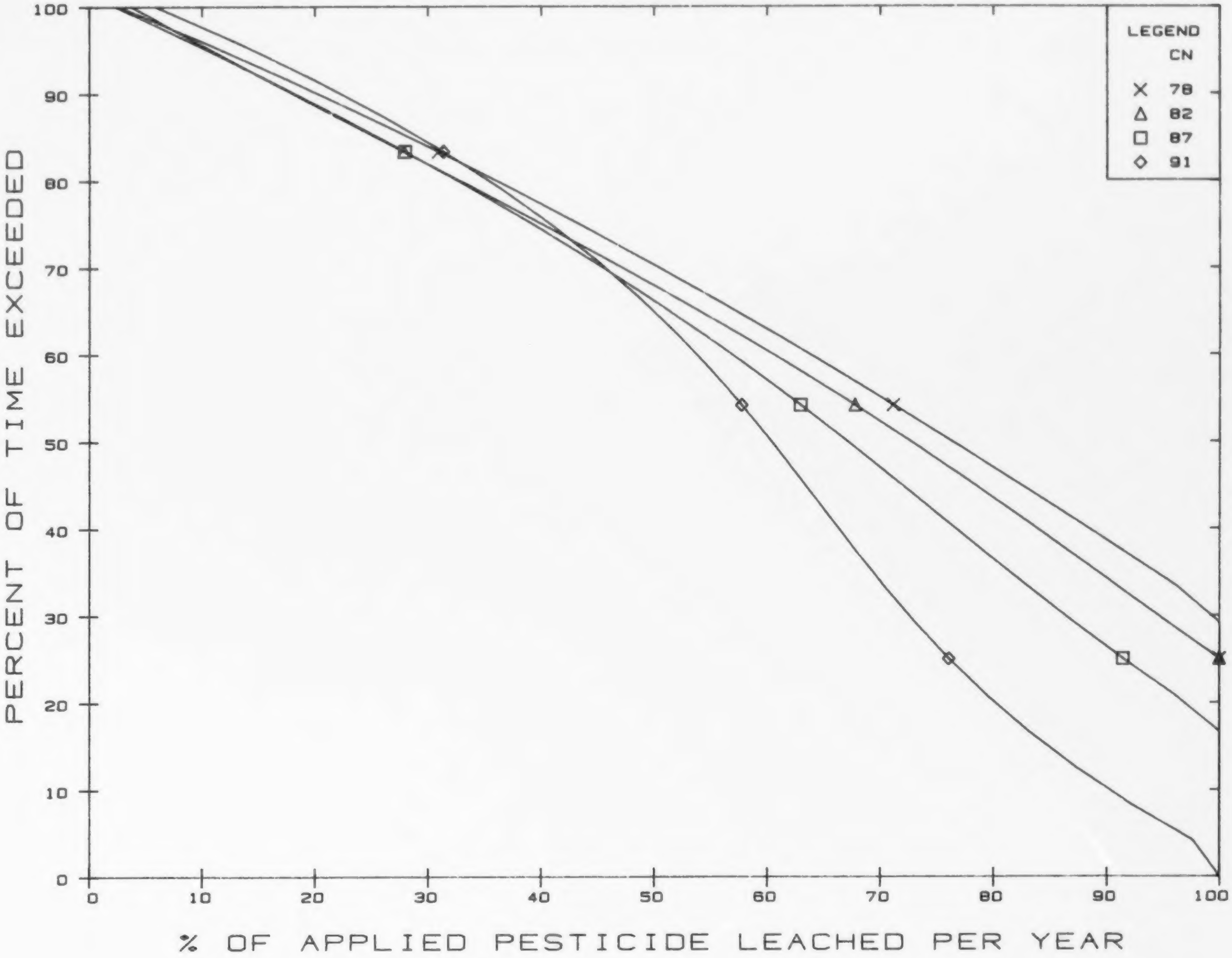


FIGURE A17-6 R=3. KS=.001

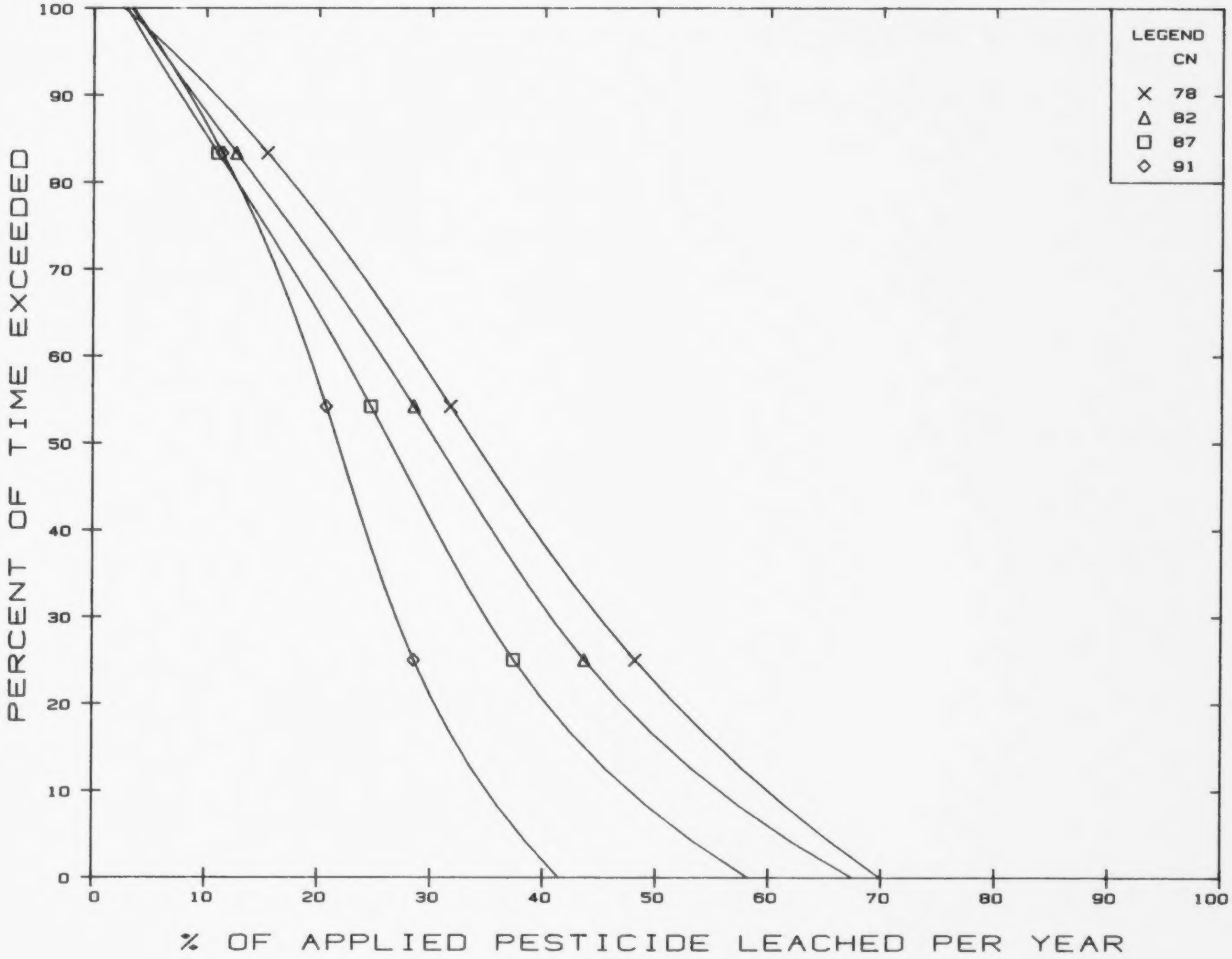


FIGURE A17-7 R=3. KS=.005

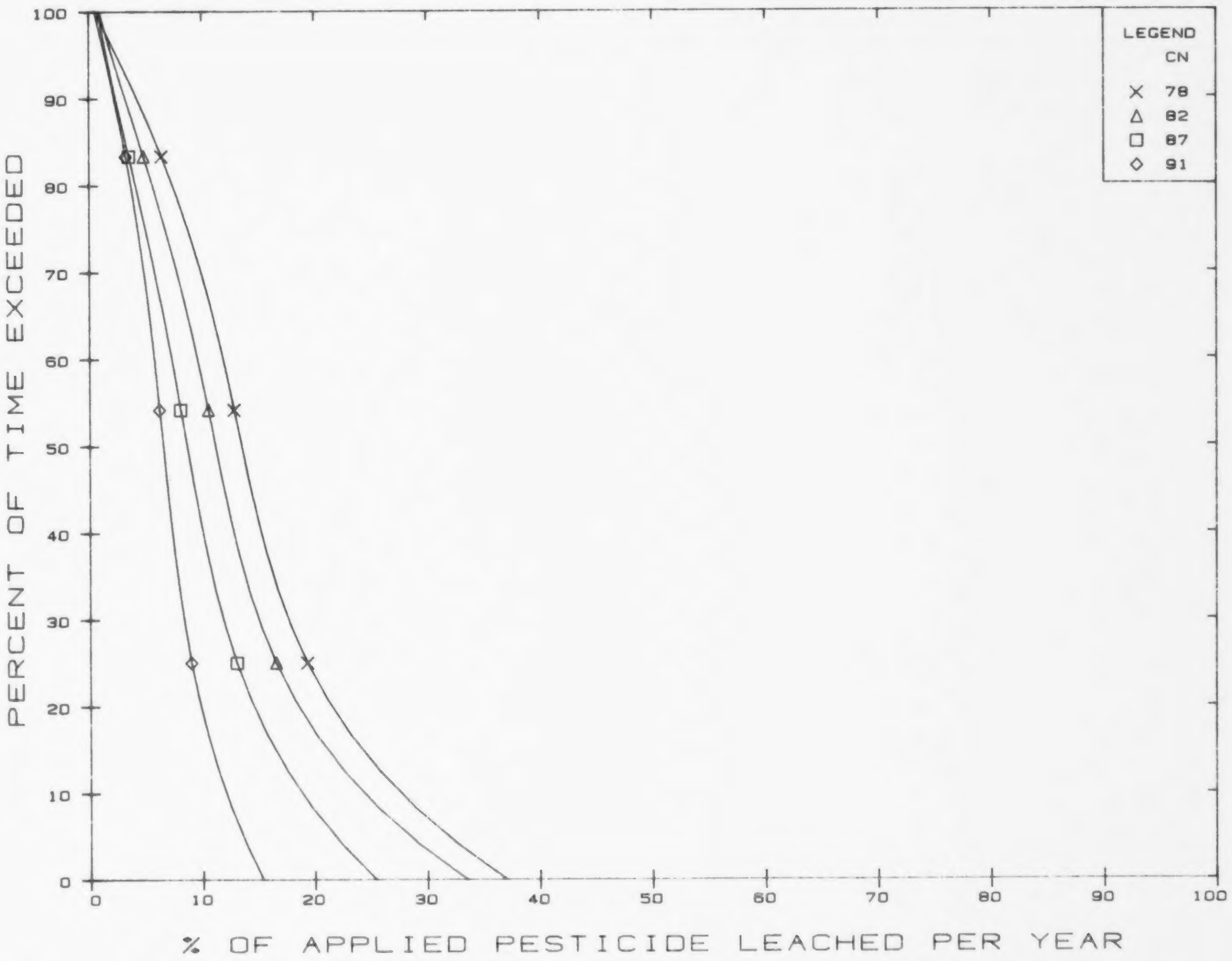


FIGURE A17-8 R=3. KS=.010

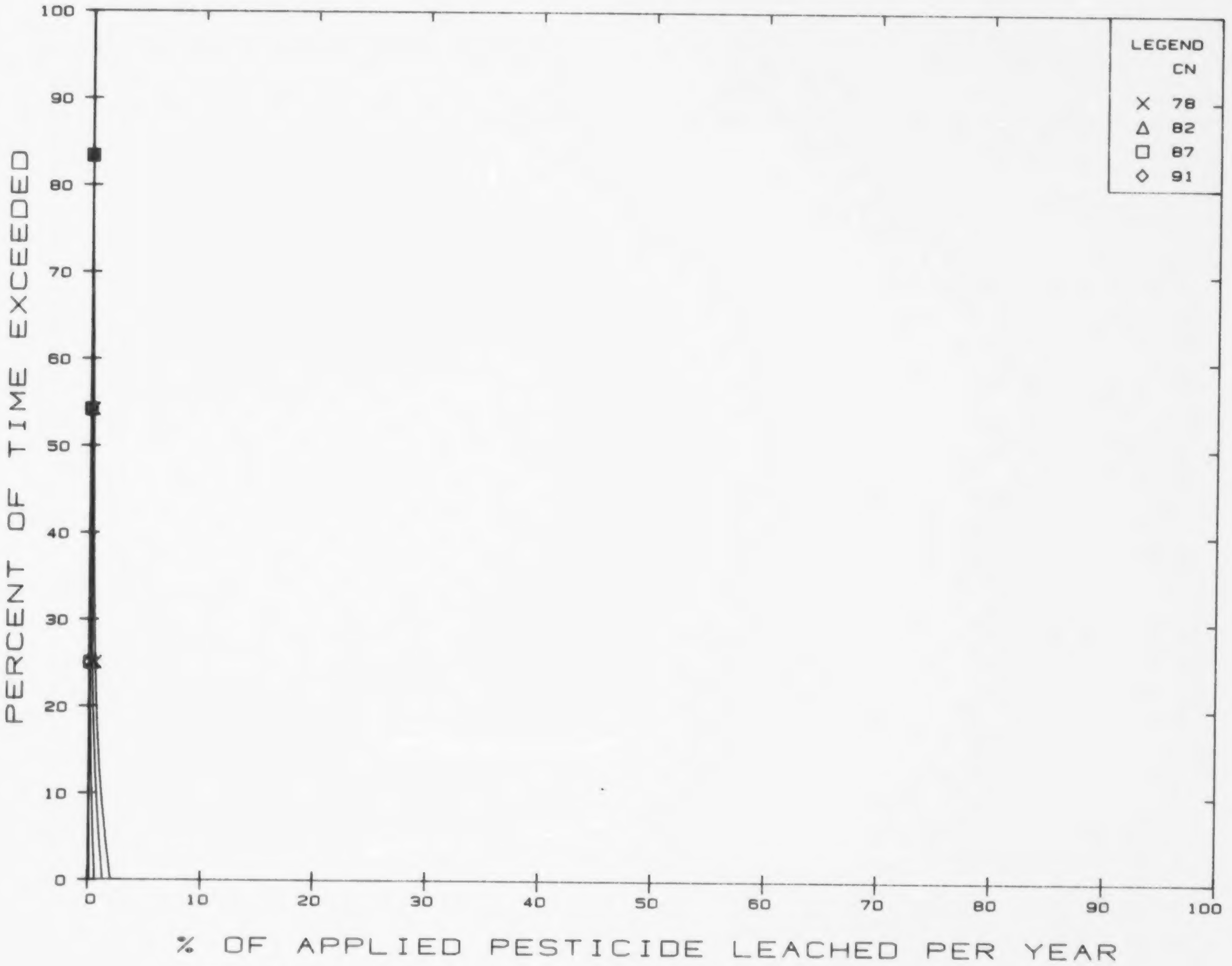


FIGURE A17-9 R=3. KS=.050

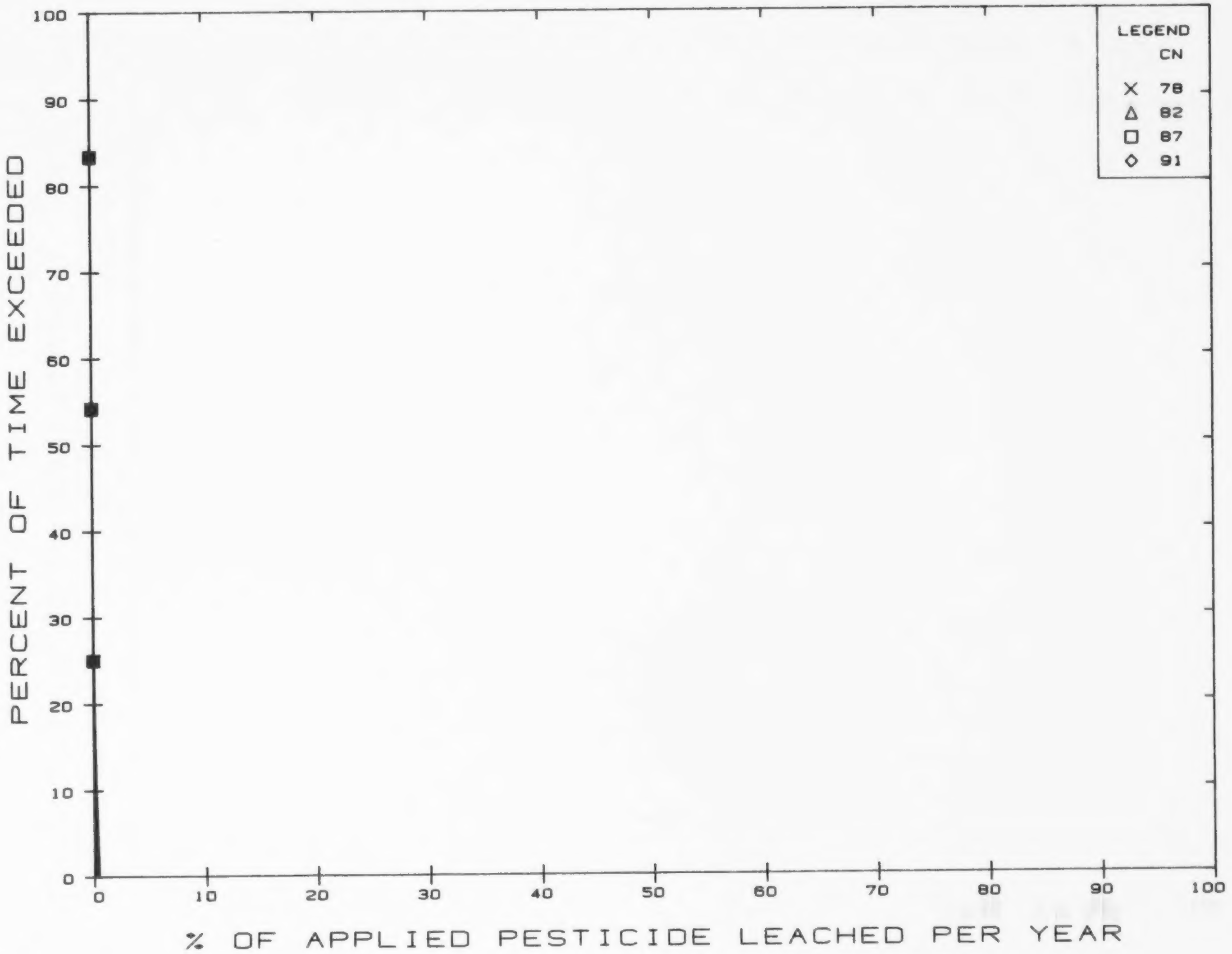


FIGURE A17-10 R=3. KS=.100

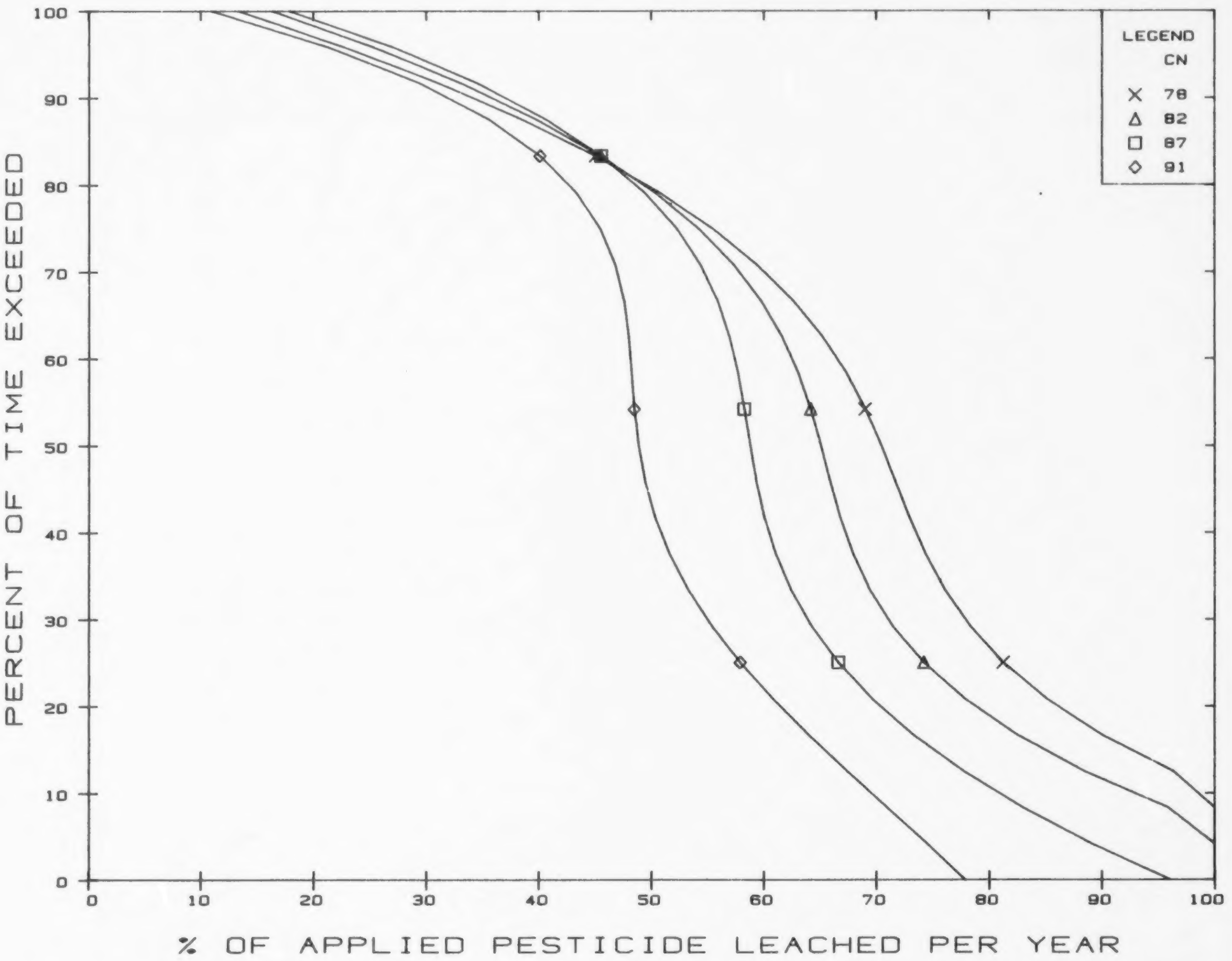


FIGURE A17-11 R=5. KS=.001

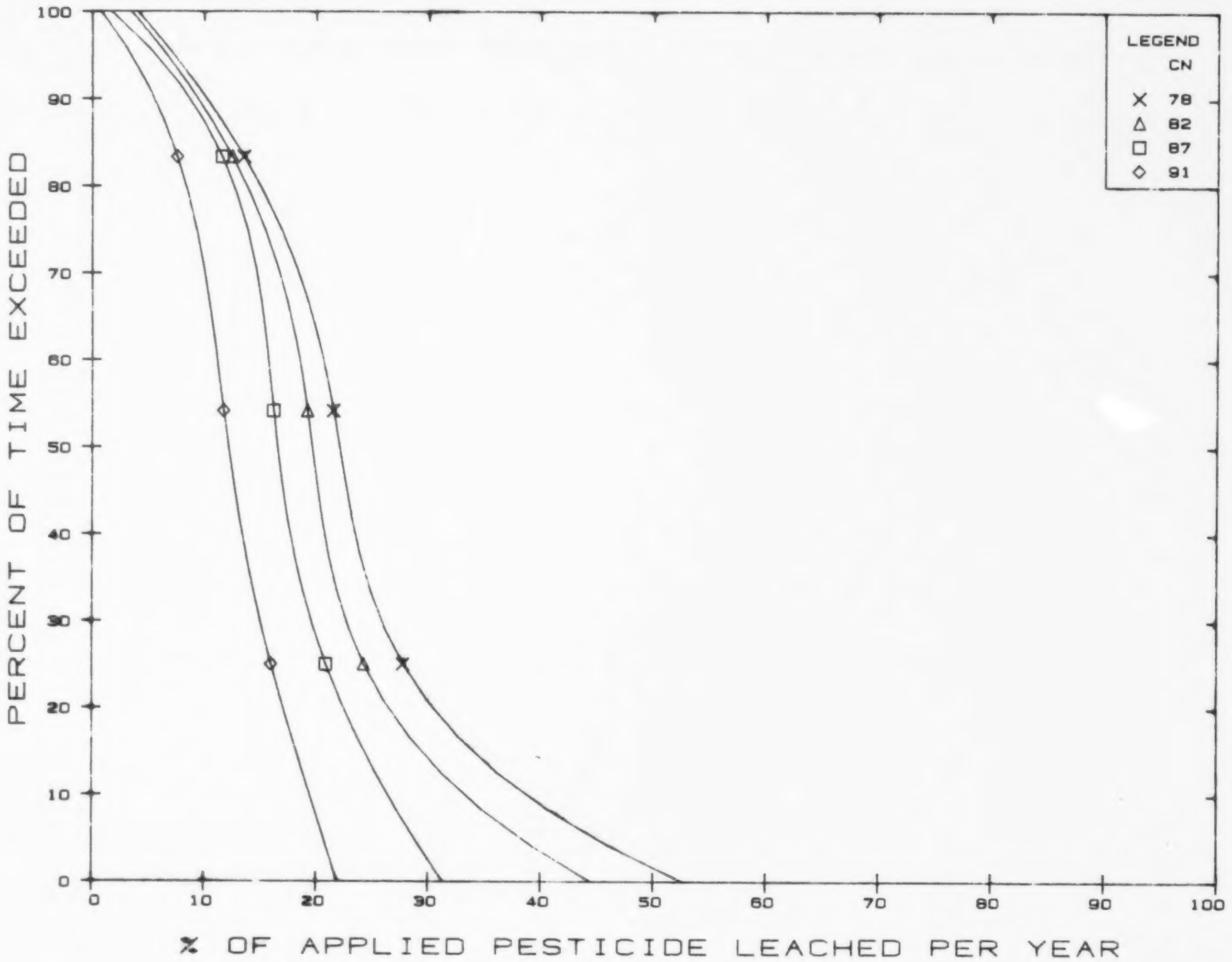
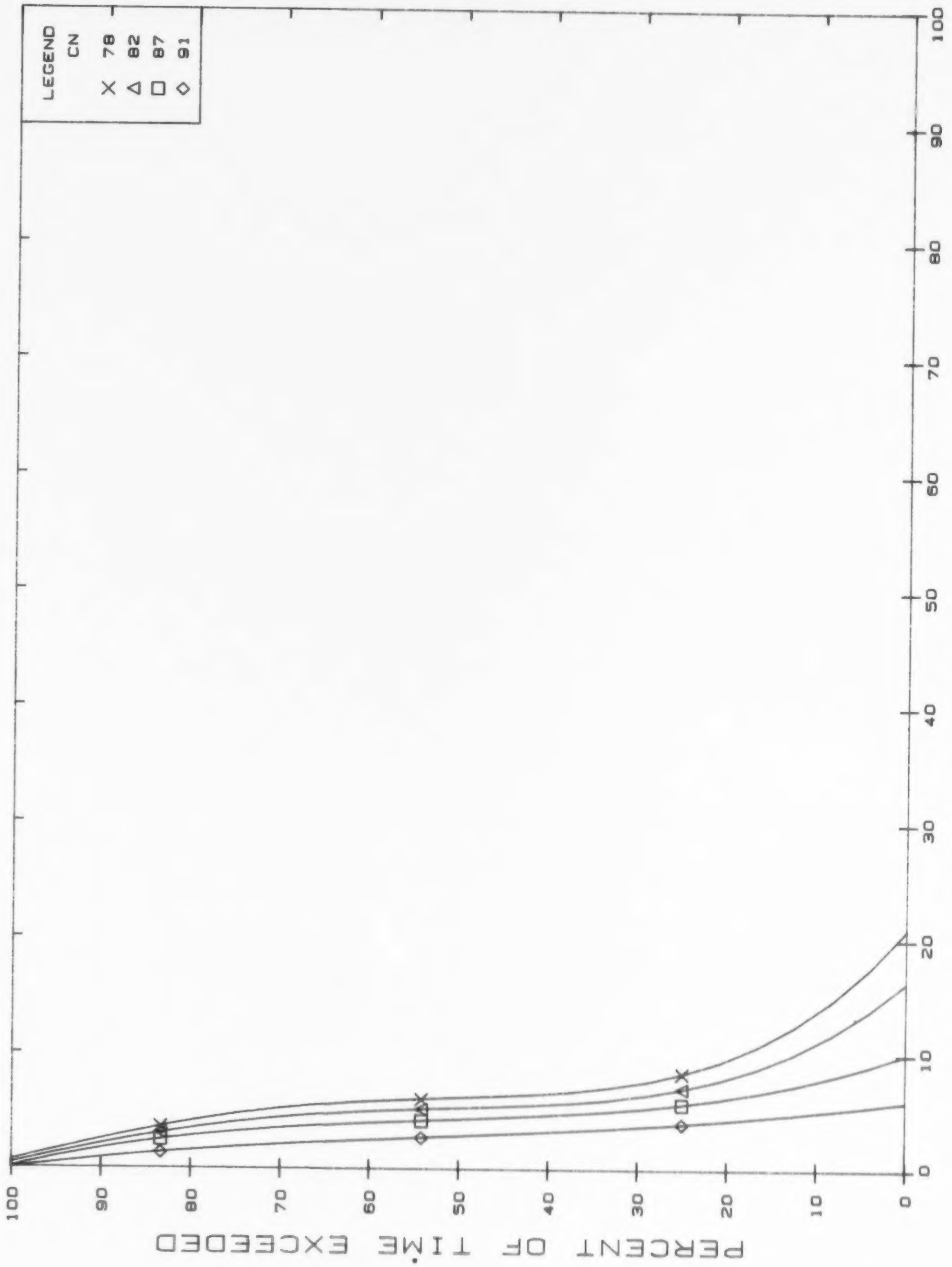


FIGURE A17-12 R=5. KS=.005



% OF APPLIED PESTICIDE LEACHED PER YEAR

FIGURE A17-13 R=5. KS=.010

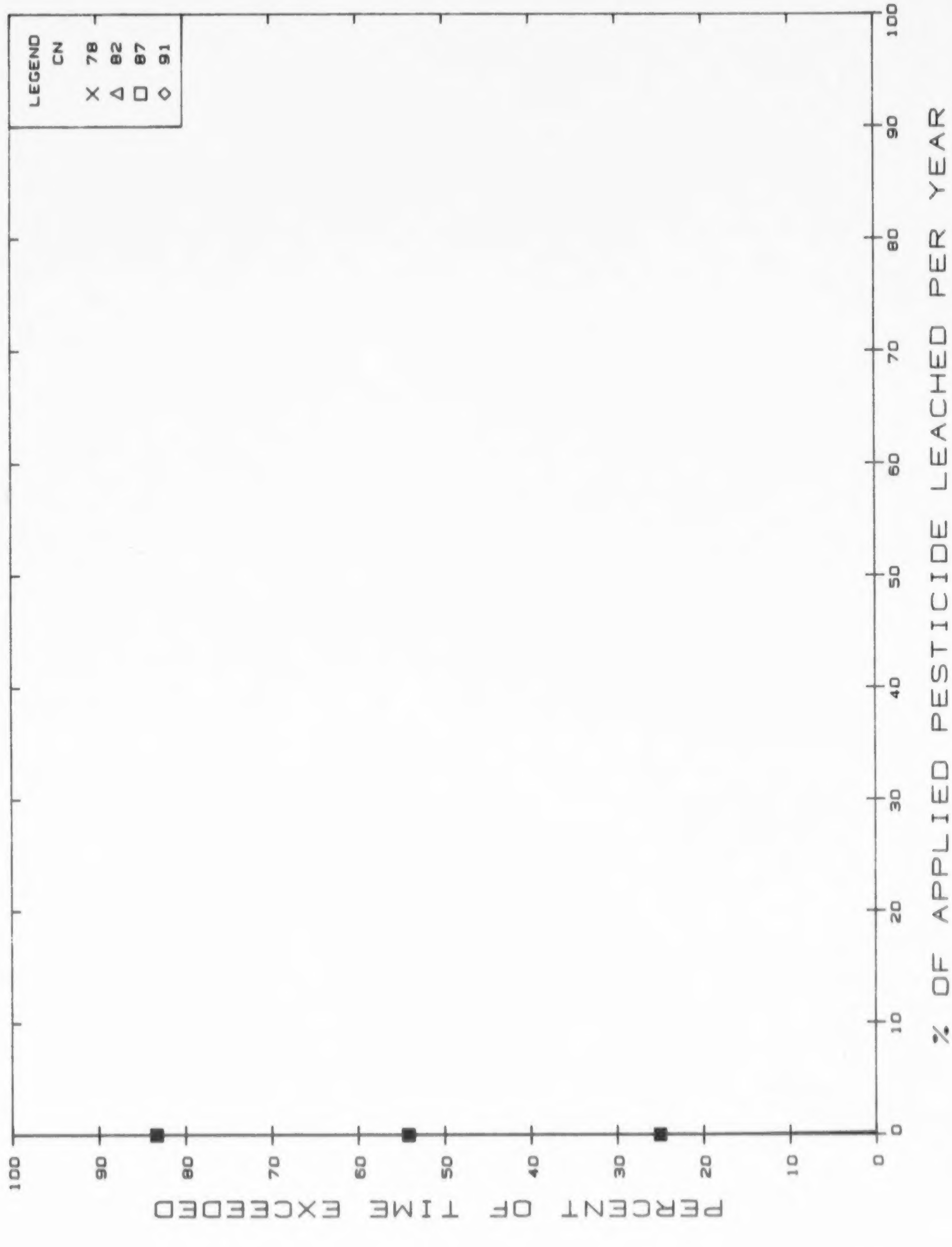


FIGURE A17-14 R=5. KS=.050

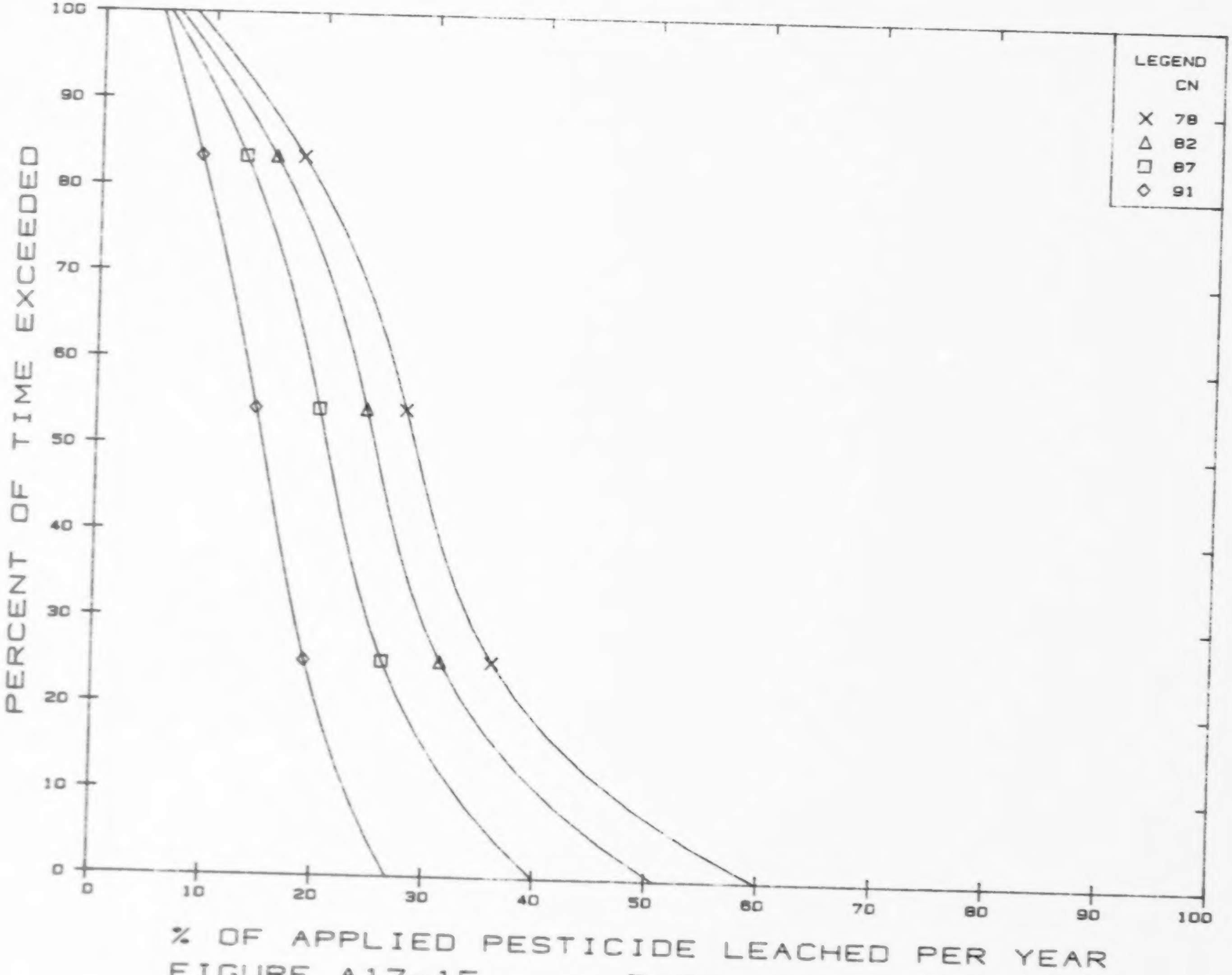


FIGURE A17-15 R=20. KS=.001

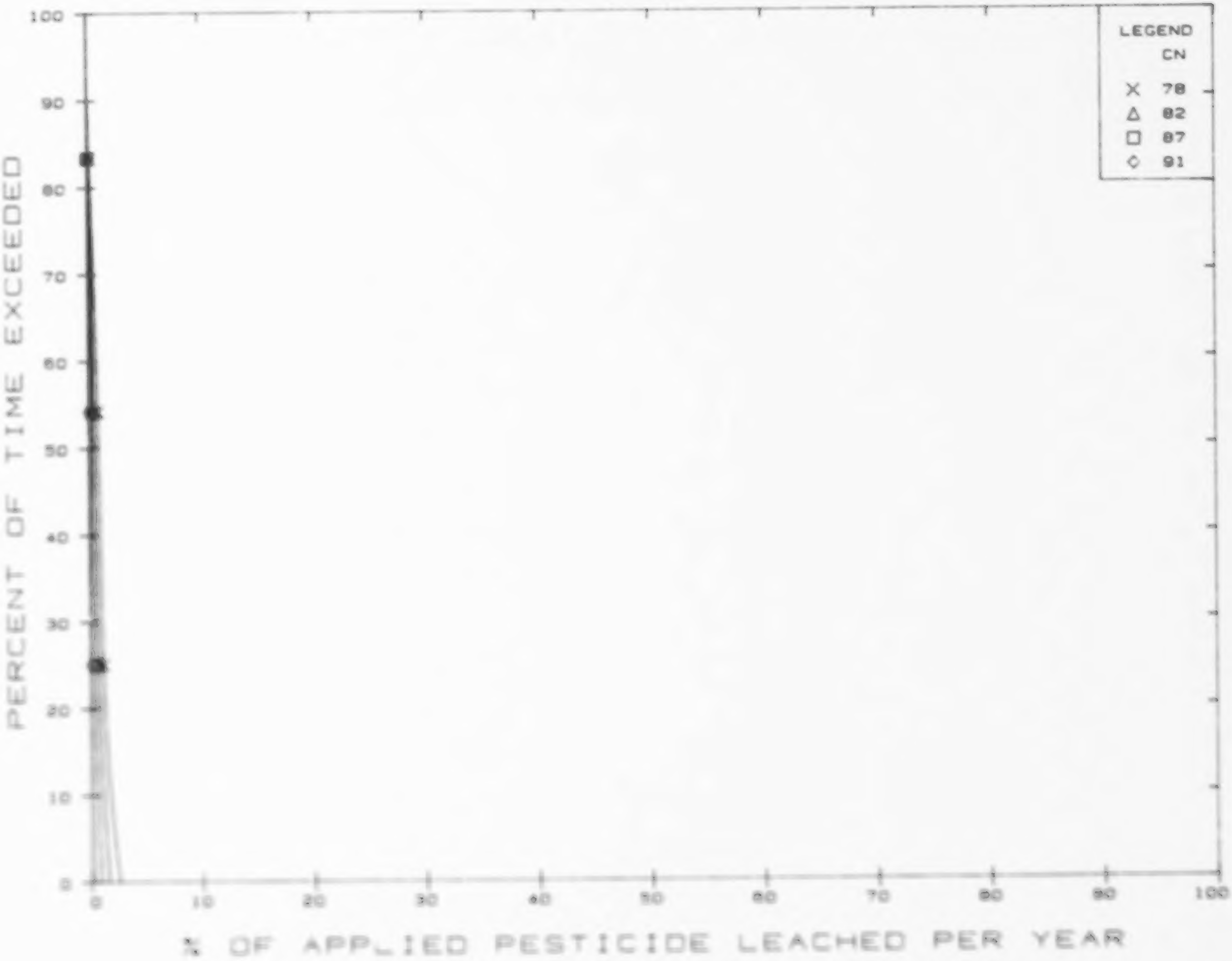


FIGURE A17-16 R=20. KS=.005

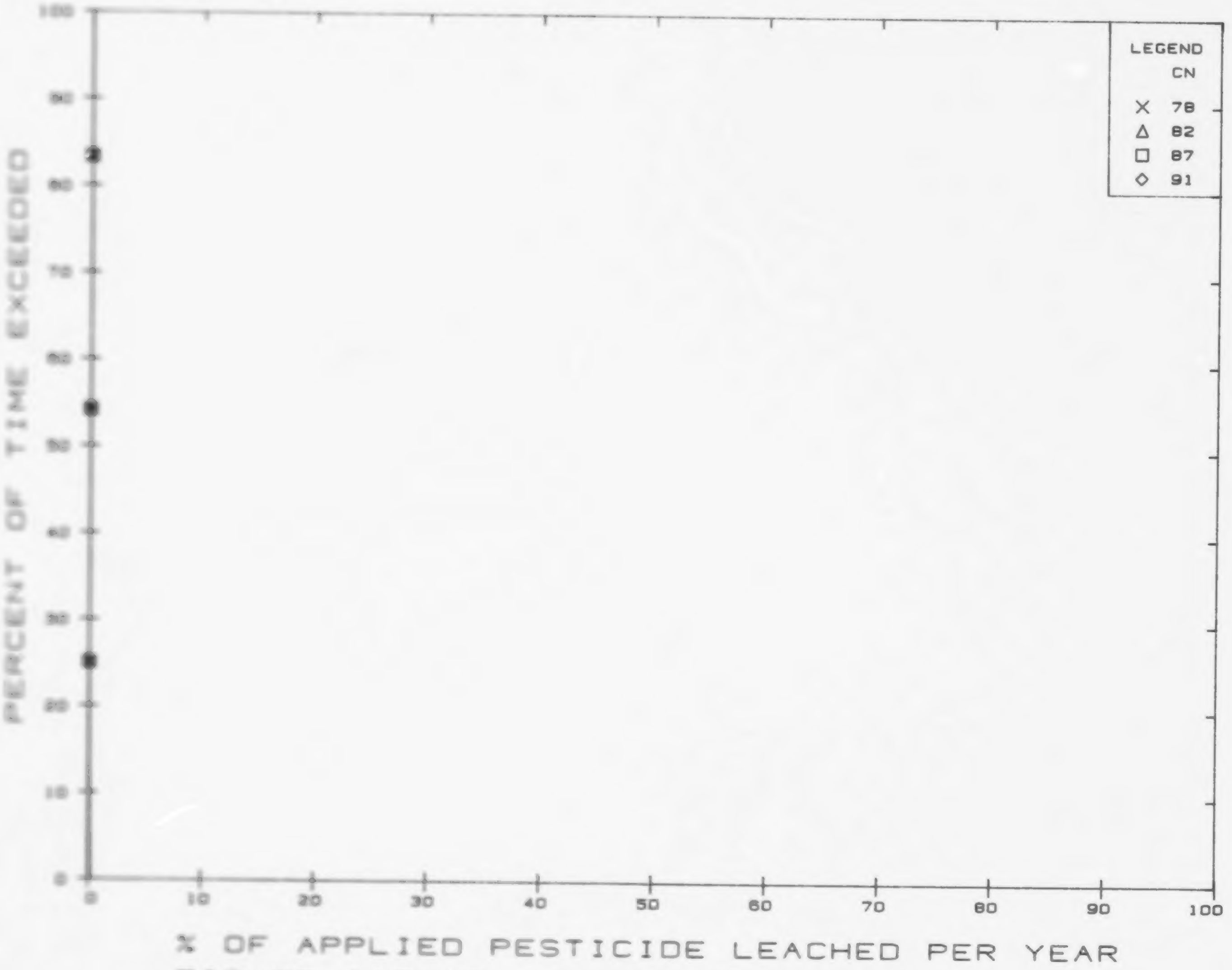


FIGURE A17-17 R=20. KS=.010

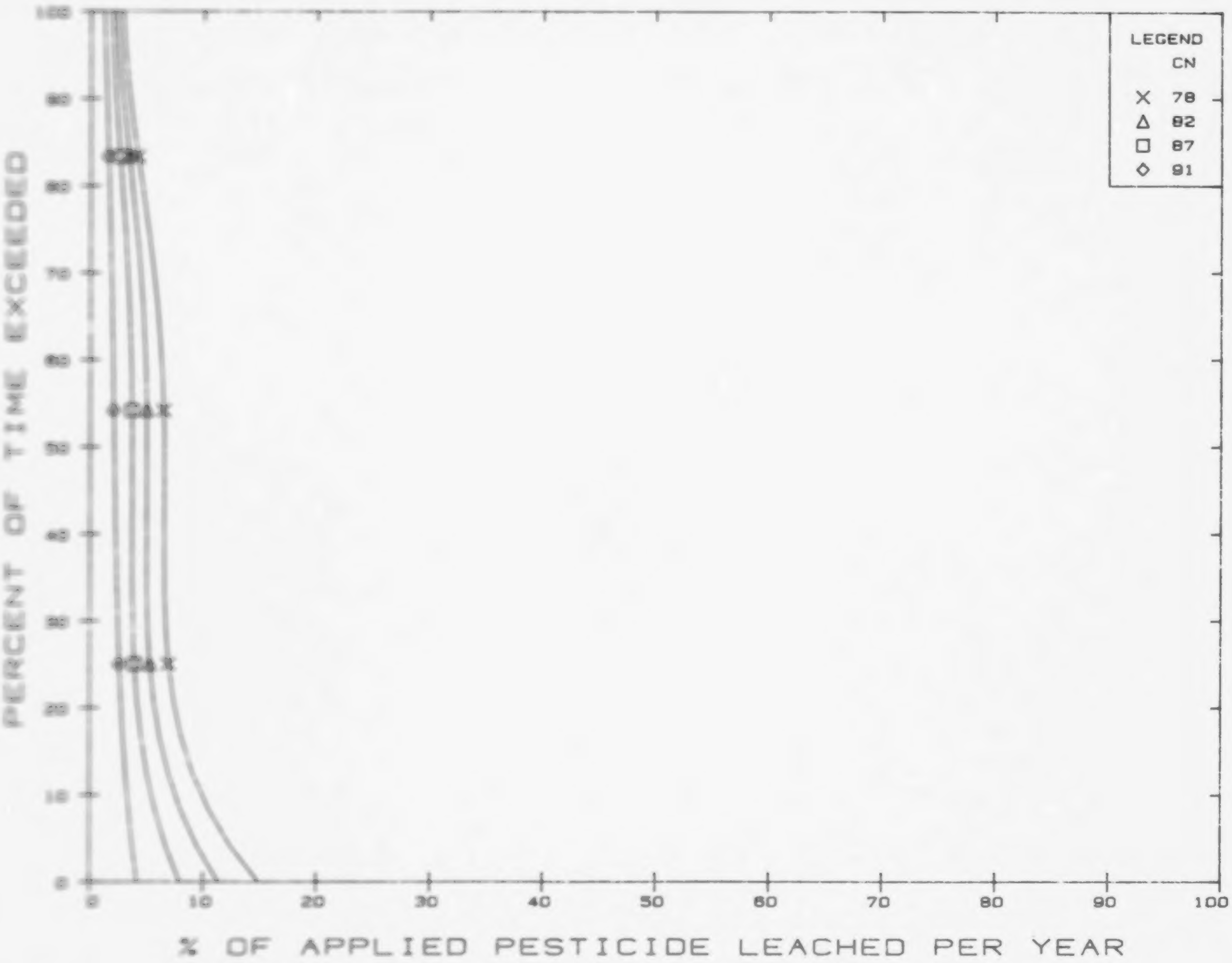


FIGURE A17-18 R=50. KS=.001

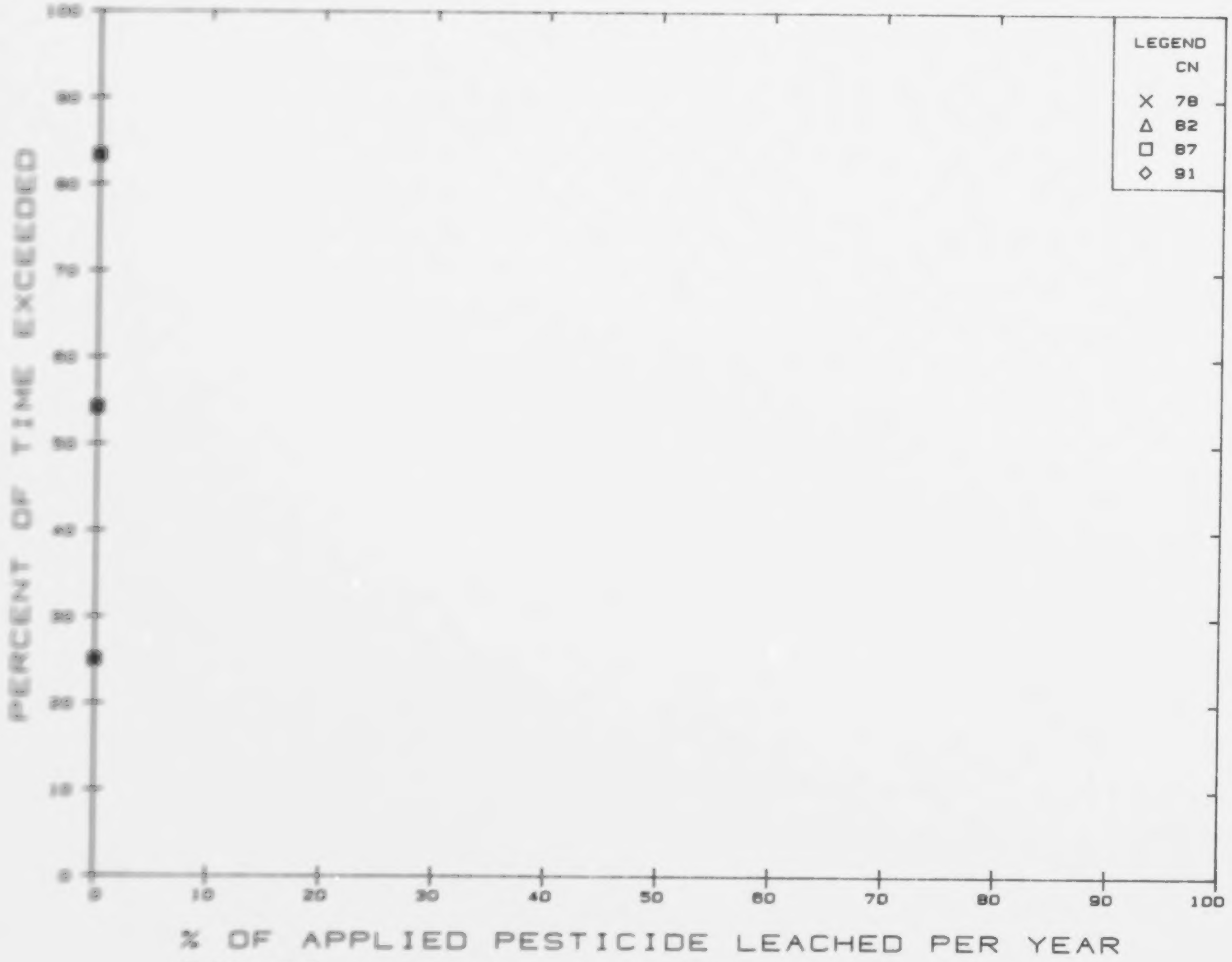
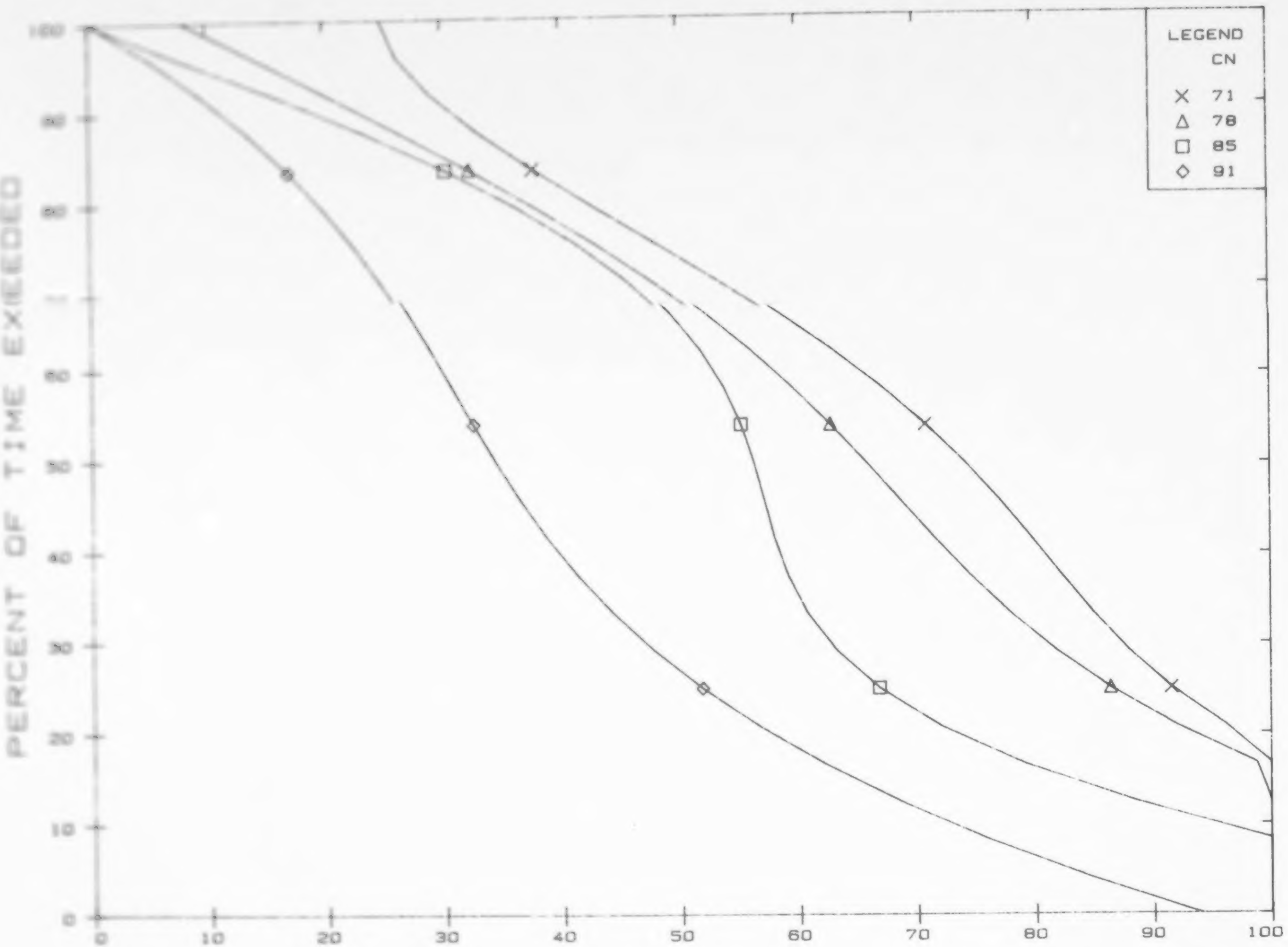


FIGURE A17-19 R=50. KS=.005



% OF APPLIED PESTICIDE LEACHED PER YEAR

FIGURE A18-1 R=1. KS=.001

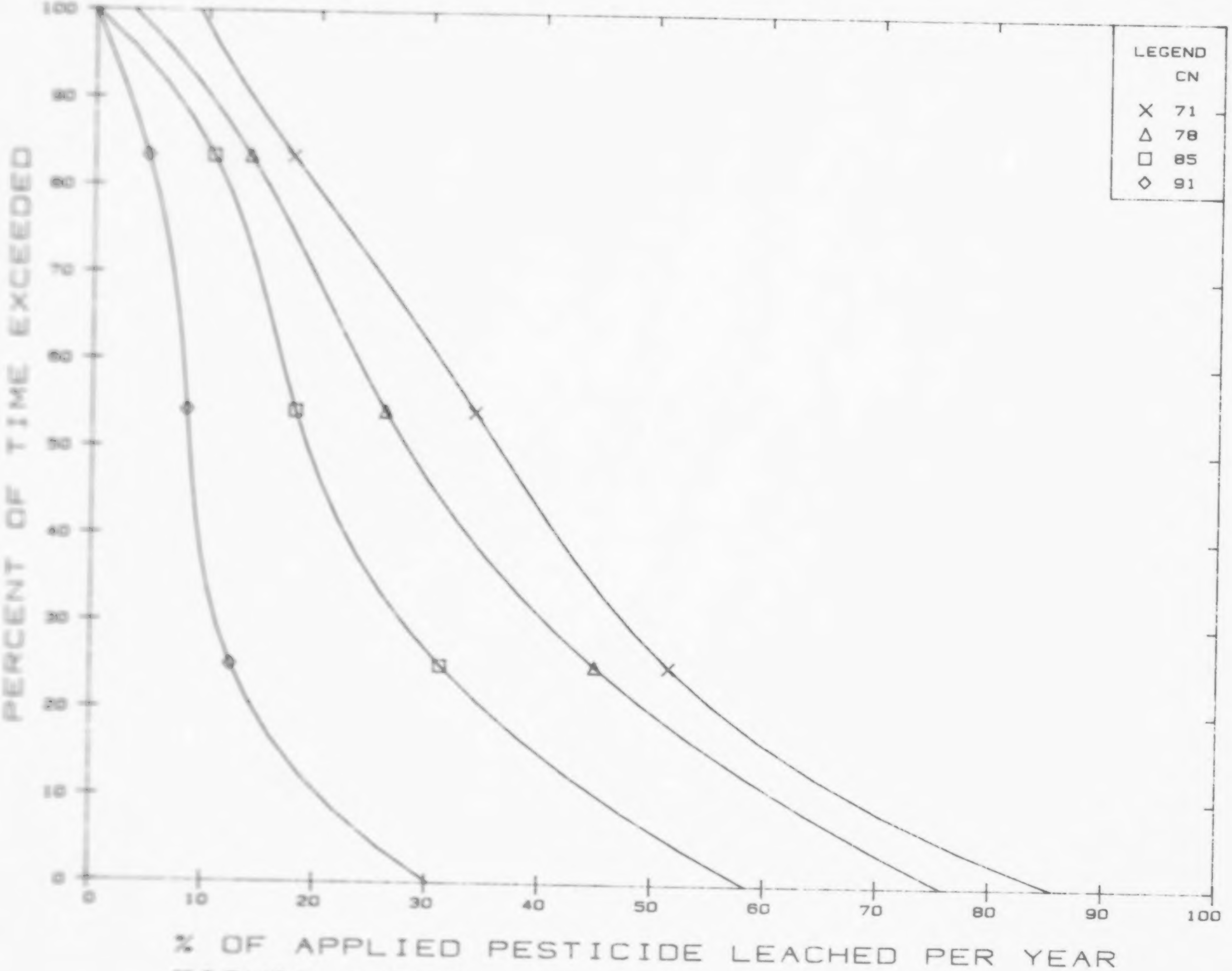
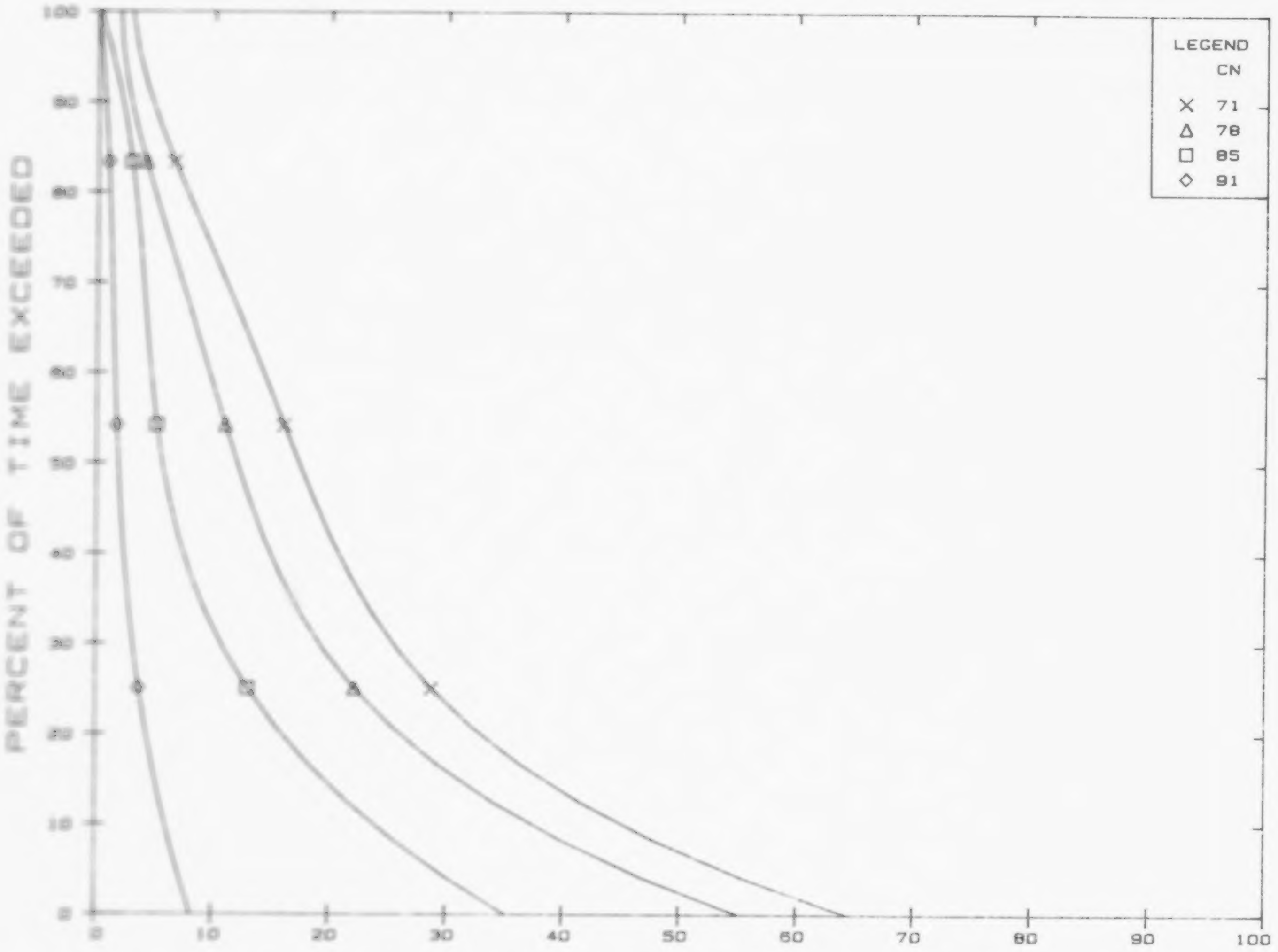
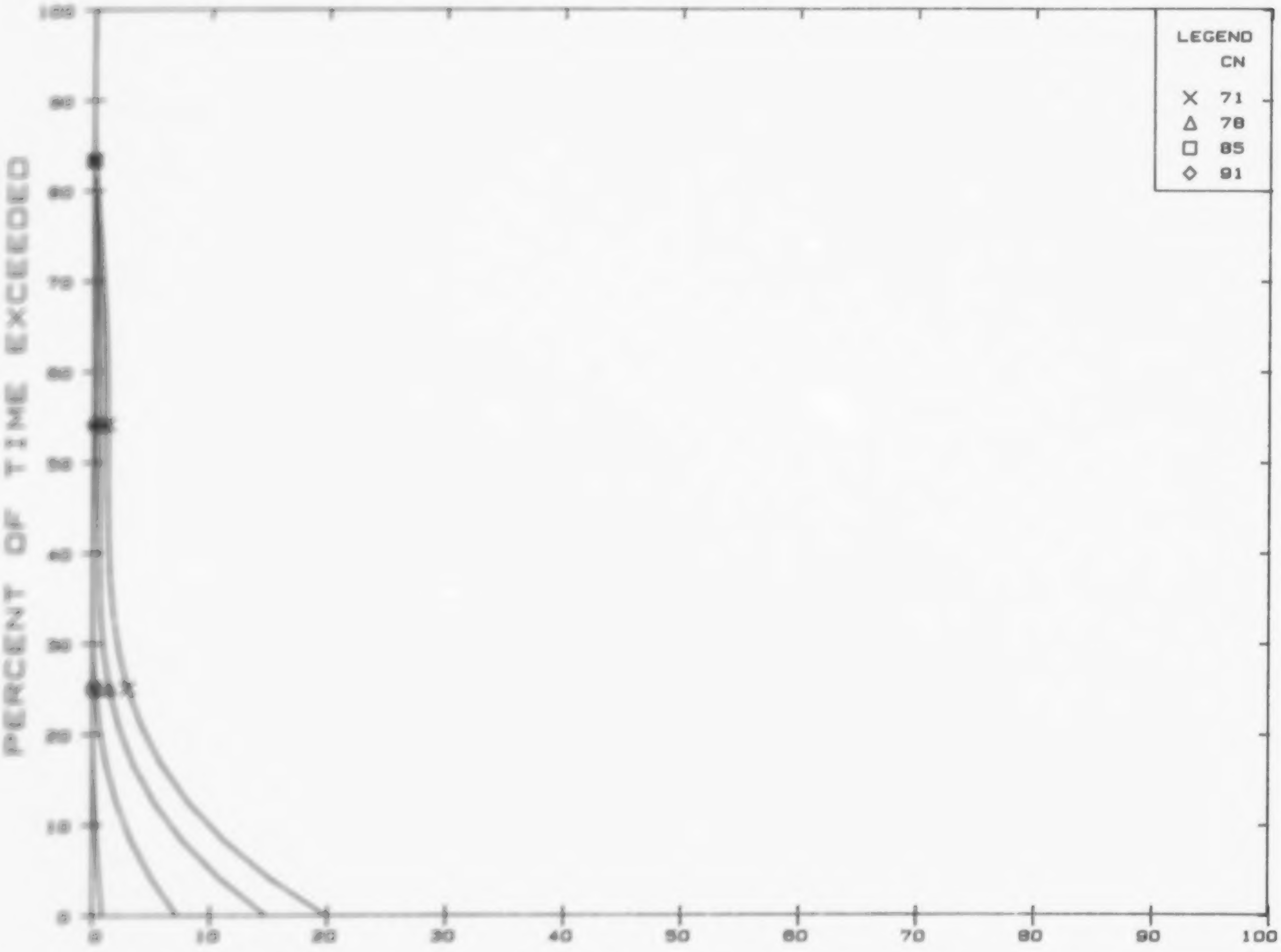


FIGURE A18-2 R=1. KS=.005



% OF APPLIED PESTICIDE LEACHED PER YEAR

FIGURE A18-3 R=1. KS=.010



% OF APPLIED PESTICIDE LEACHED PER YEAR
FIGURE A18-4 R=1. KS=.050

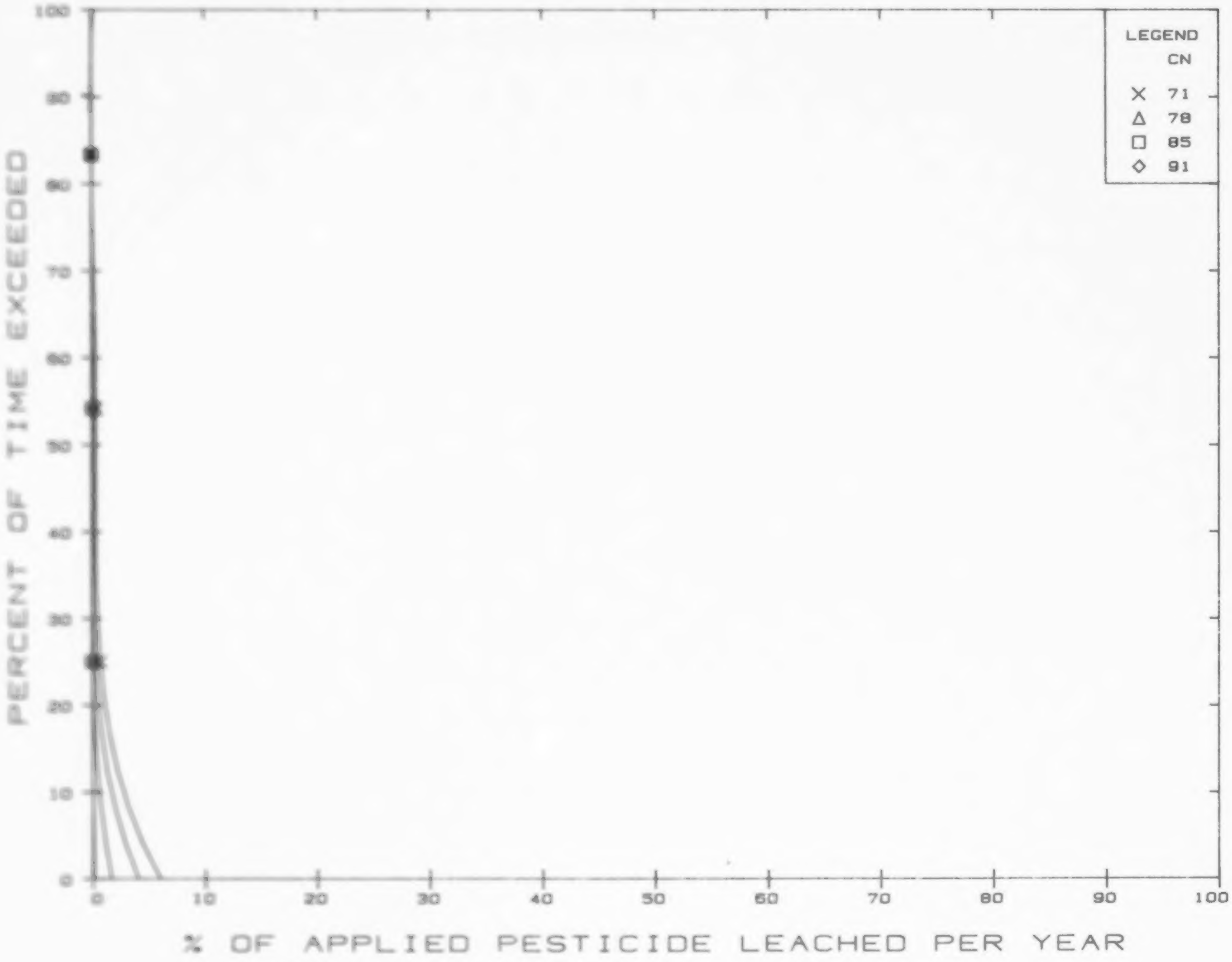


FIGURE A18-5 R=1. KS=.100

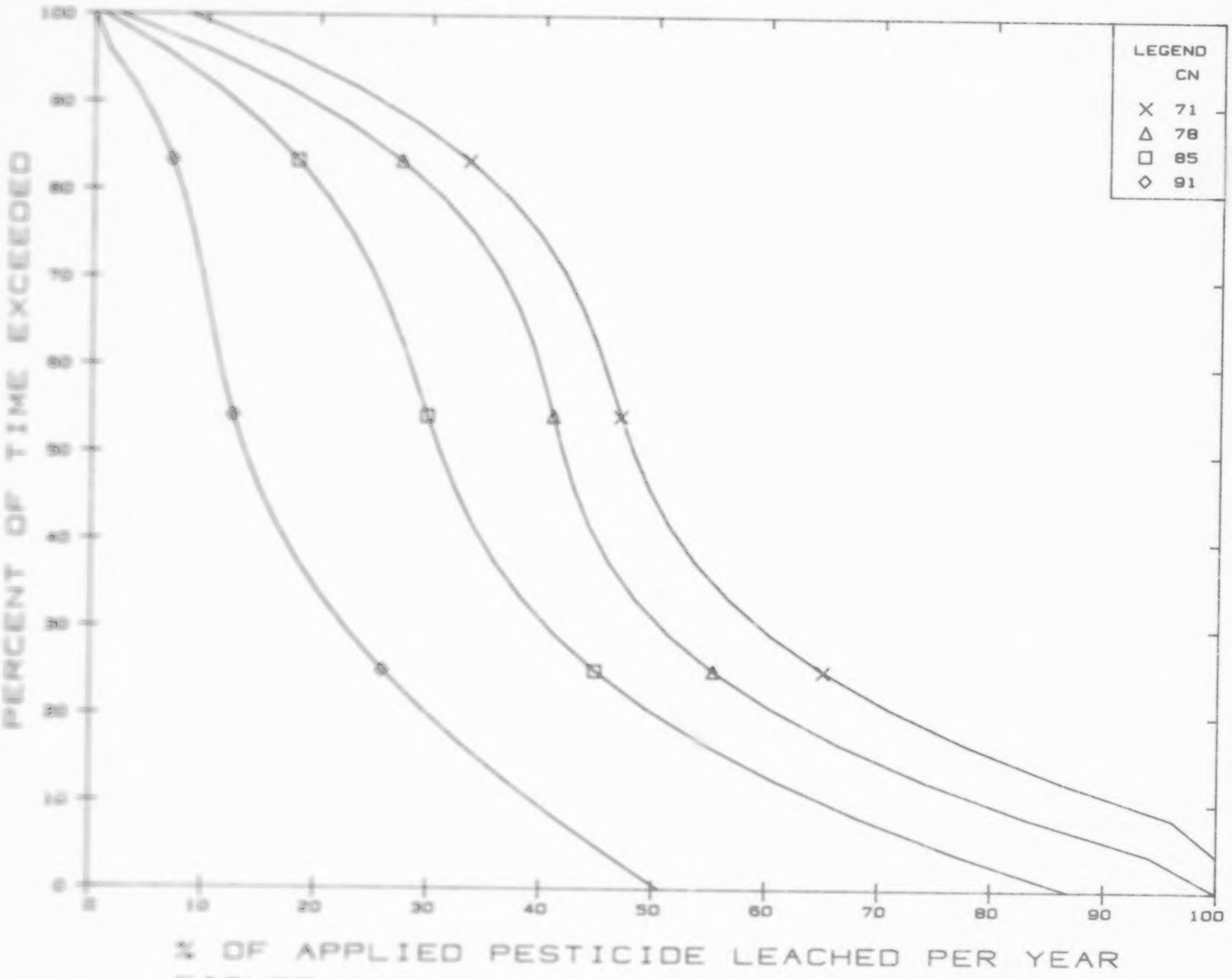


FIGURE A18-6 R=3. KS=.001

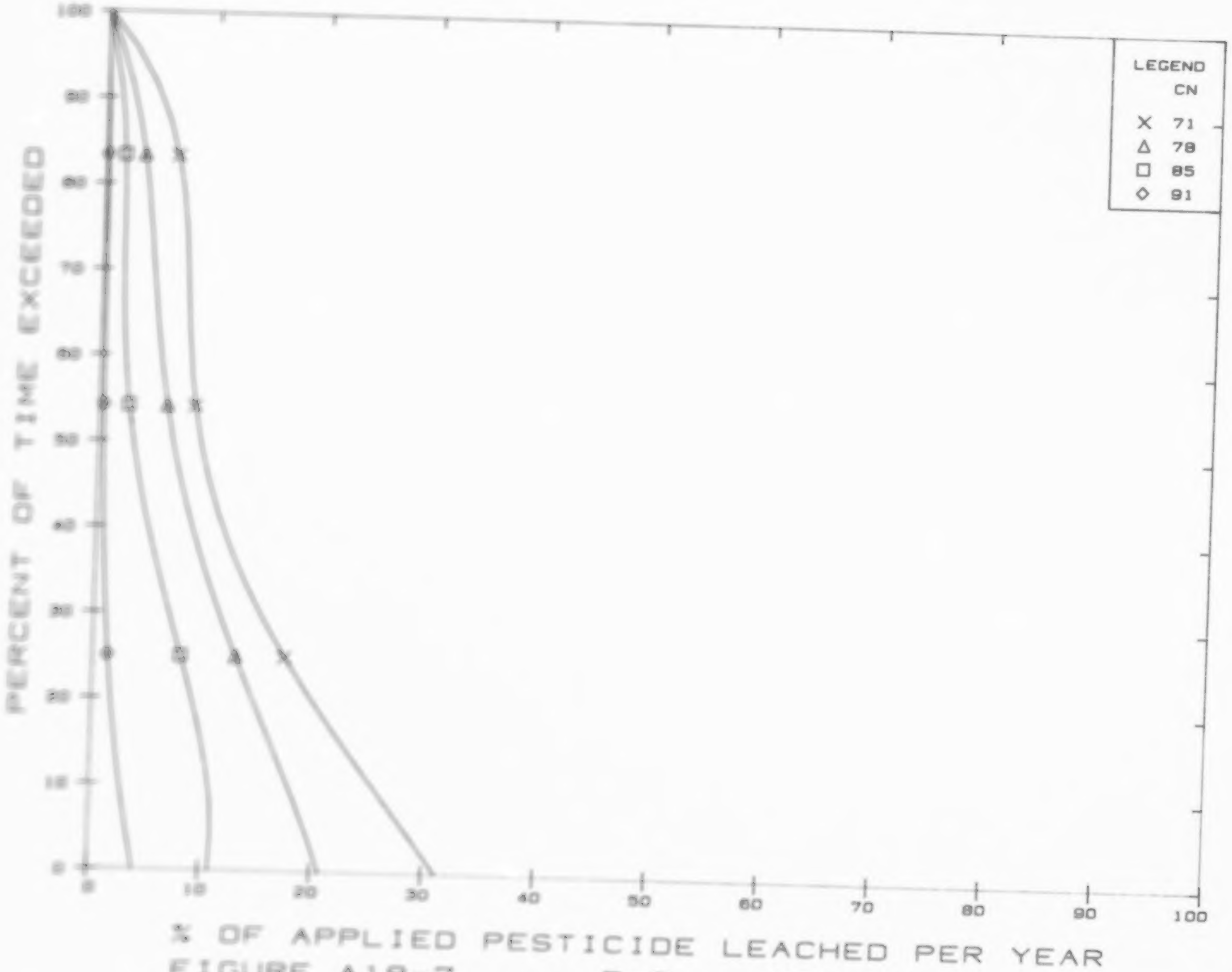
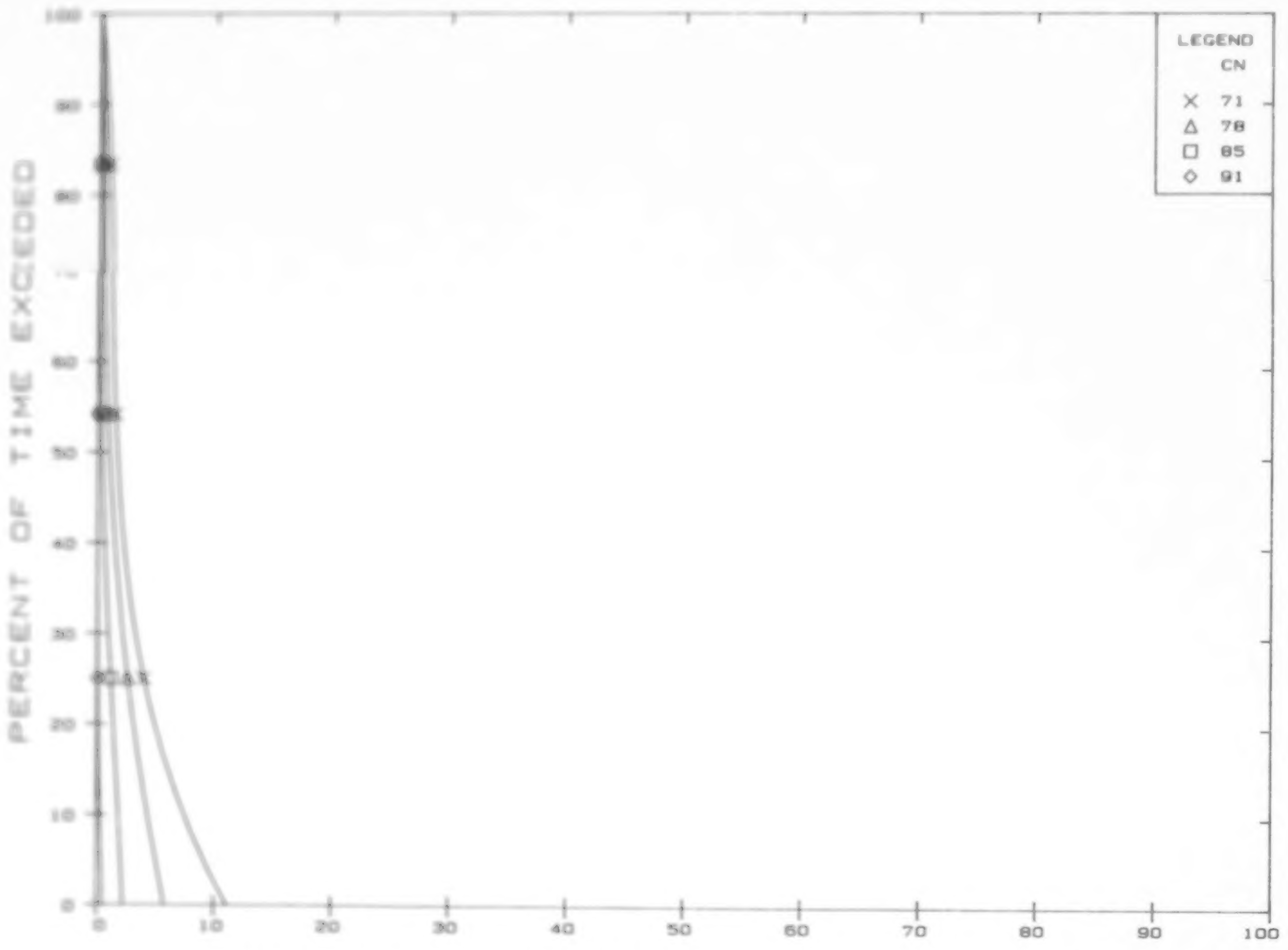


FIGURE A18-7 R=3. KS=.005



% OF APPLIED PESTICIDE LEACHED PER YEAR
FIGURE A18-8 R=3. KS=.010

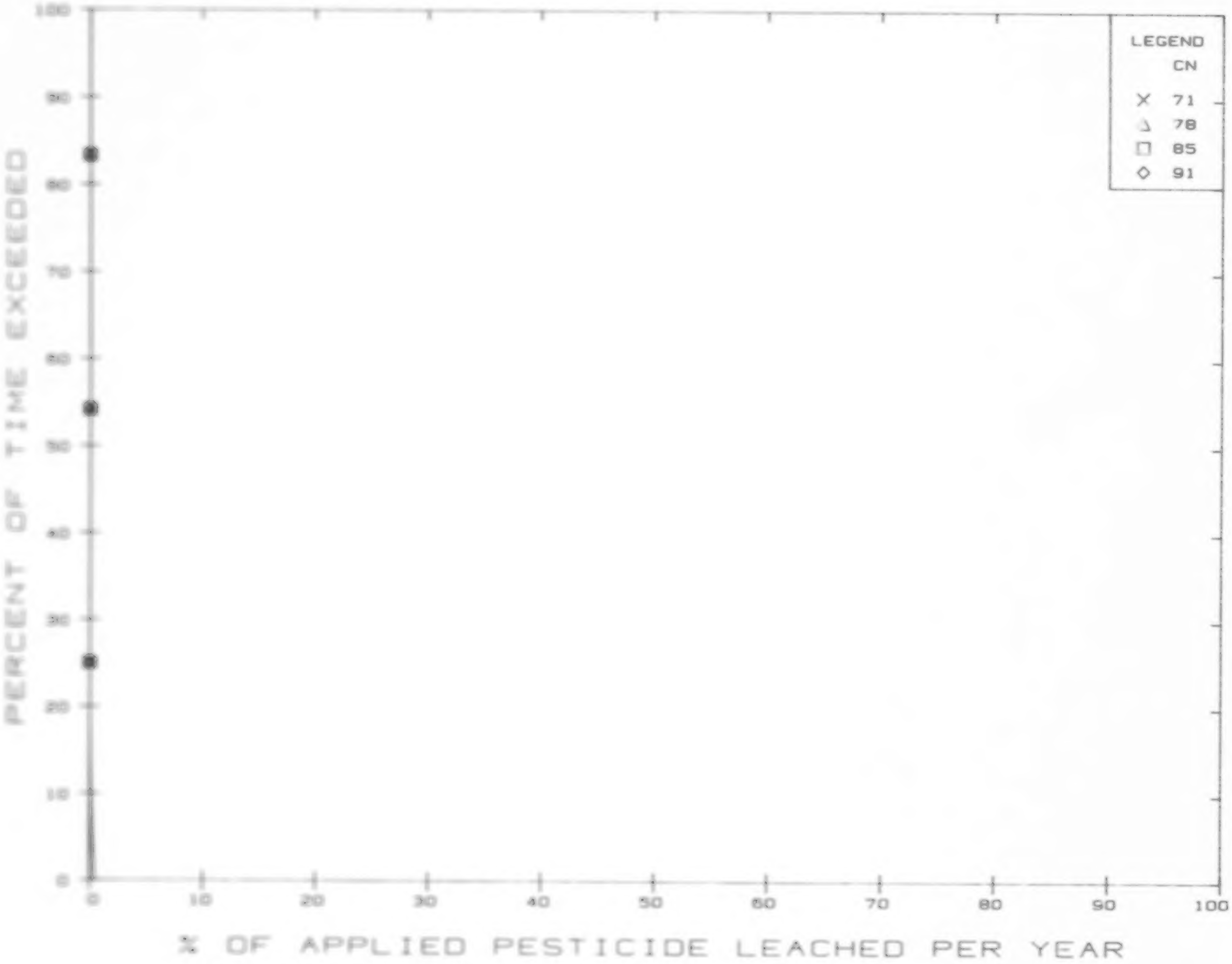


FIGURE A18-9 R=3. KS=.050

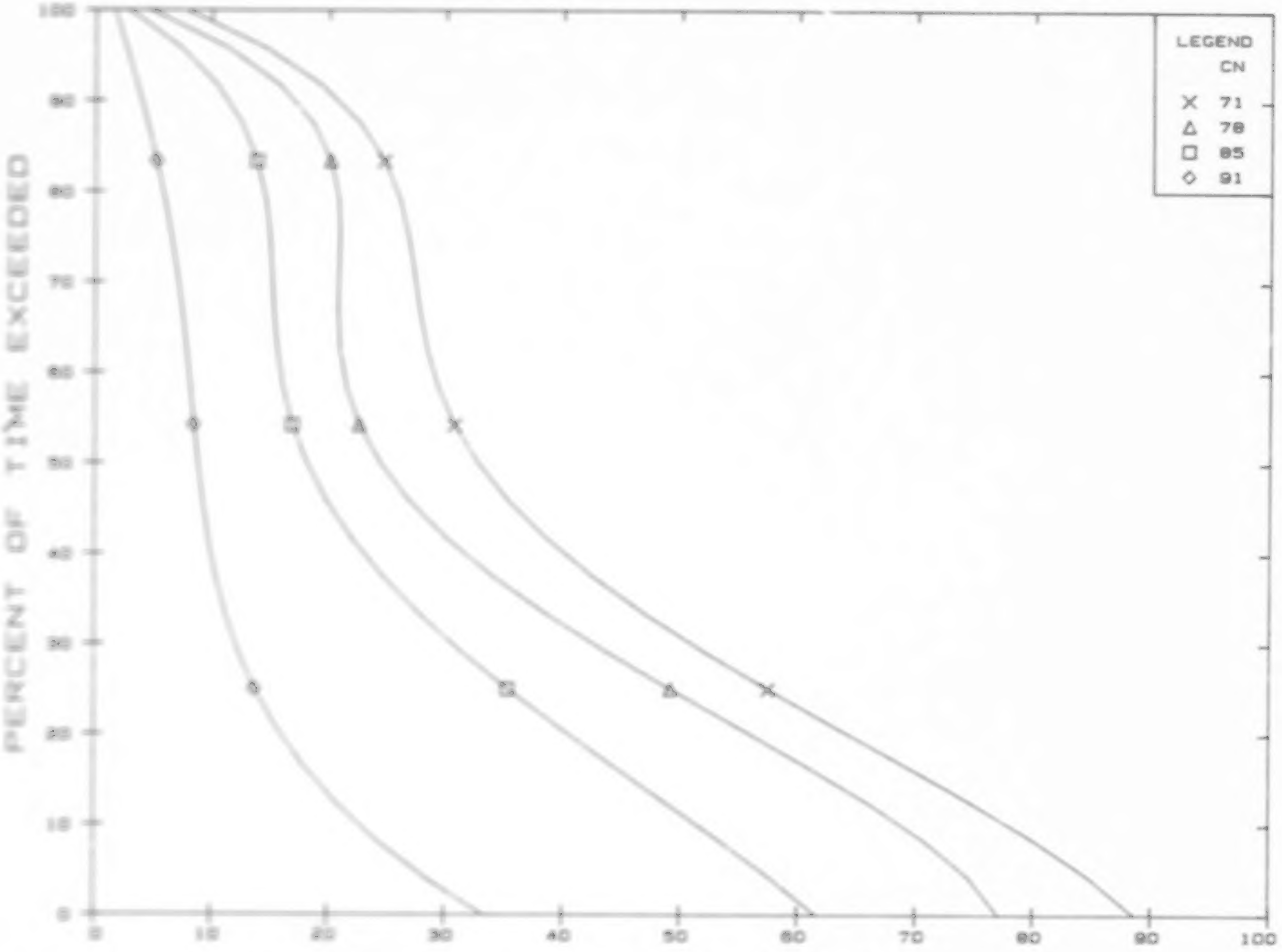


FIGURE A18-10 R=5. KS=.001

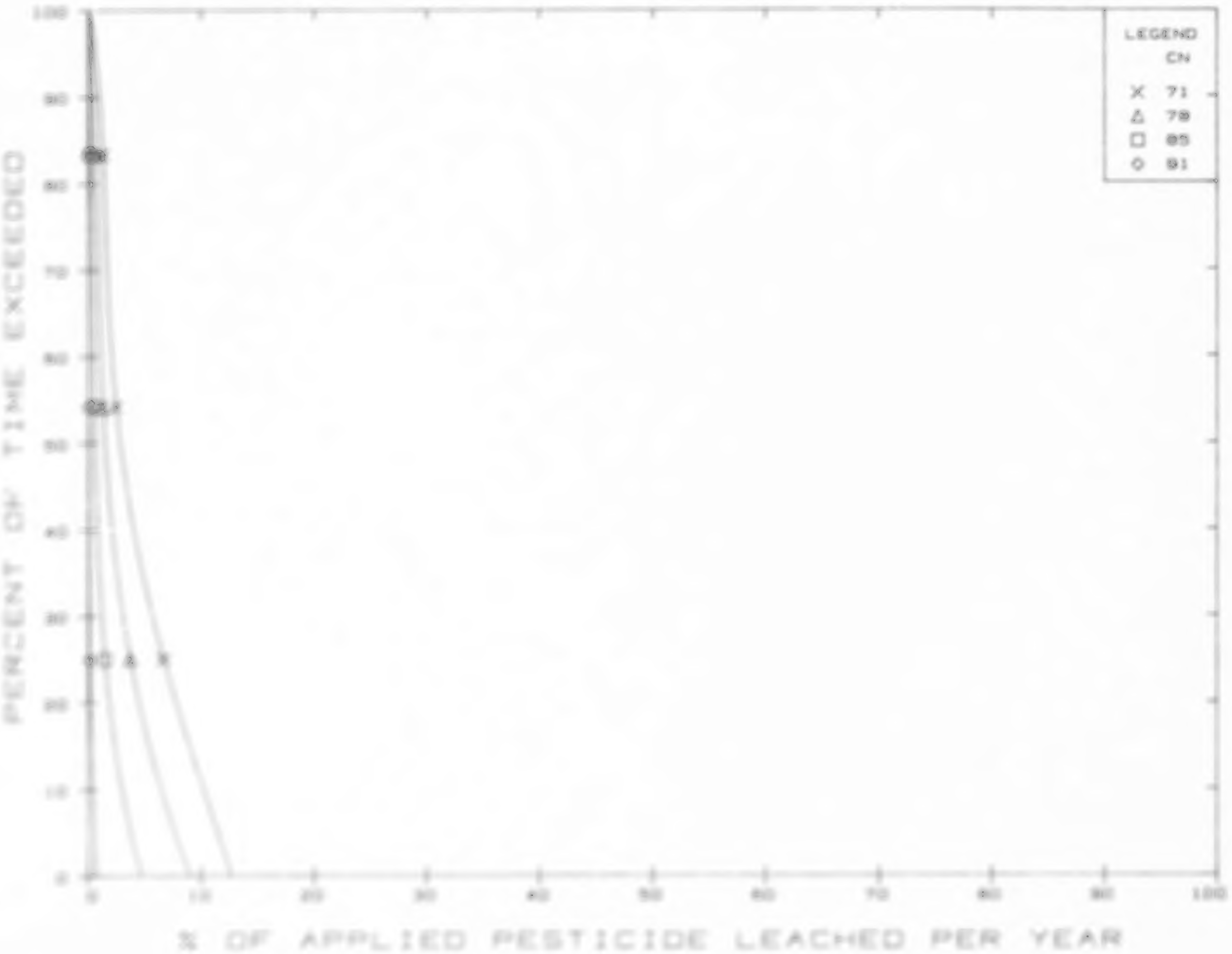


FIGURE A18-11 R=5. KS=.005

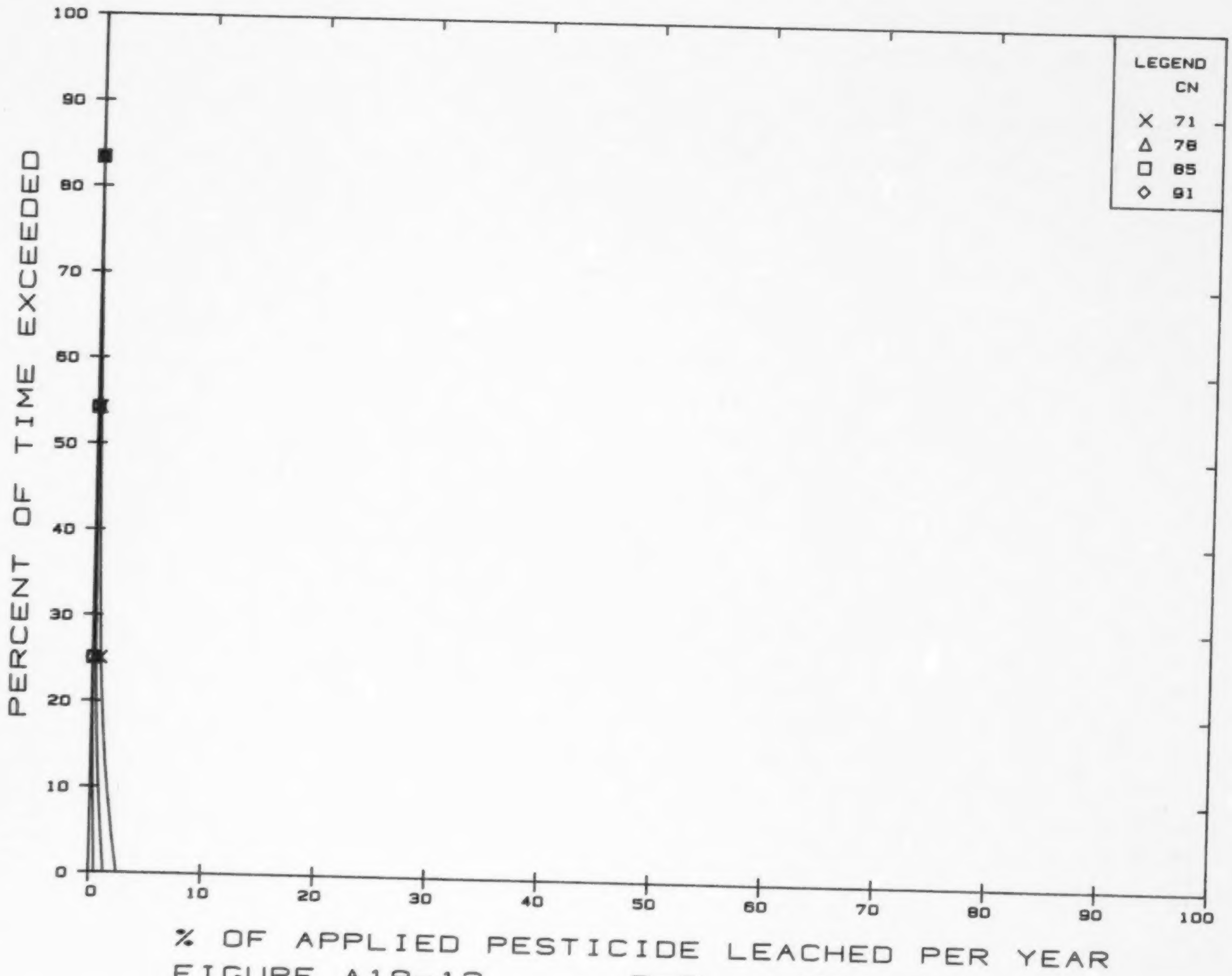


FIGURE A18-12 R=5. KS=.010

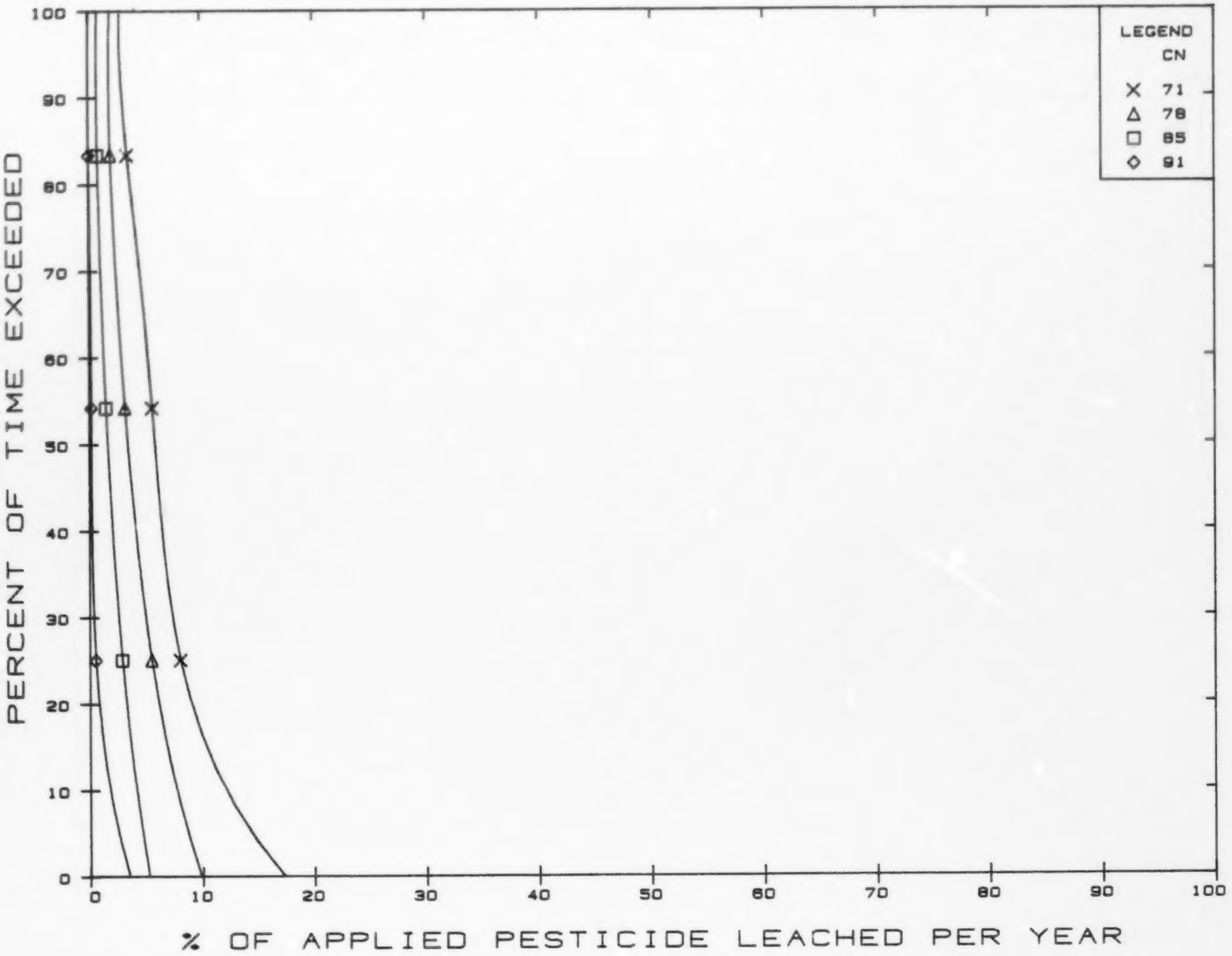


FIGURE A18-13 R=20. KS=.001

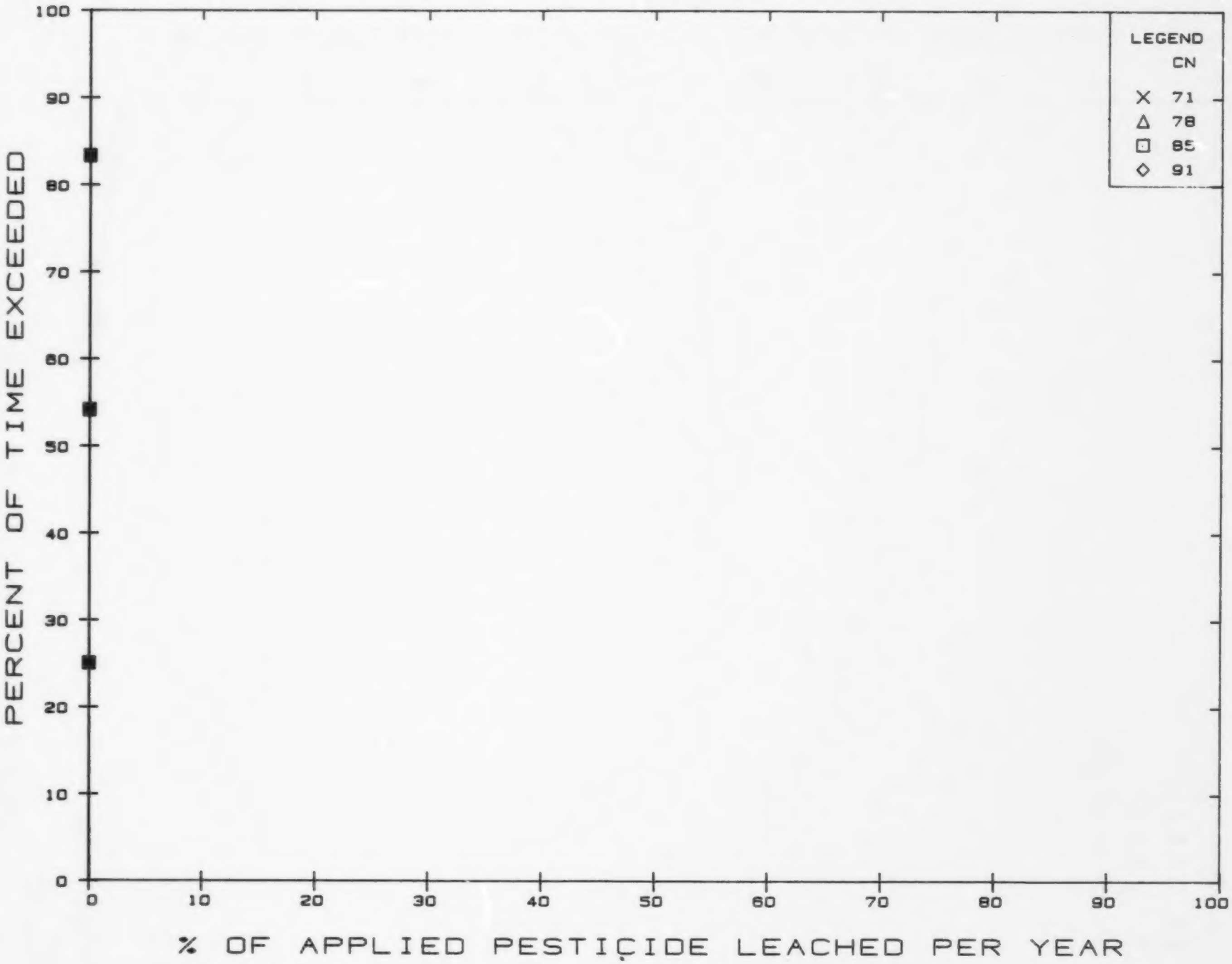


FIGURE A18-14 R=20. KS=.005

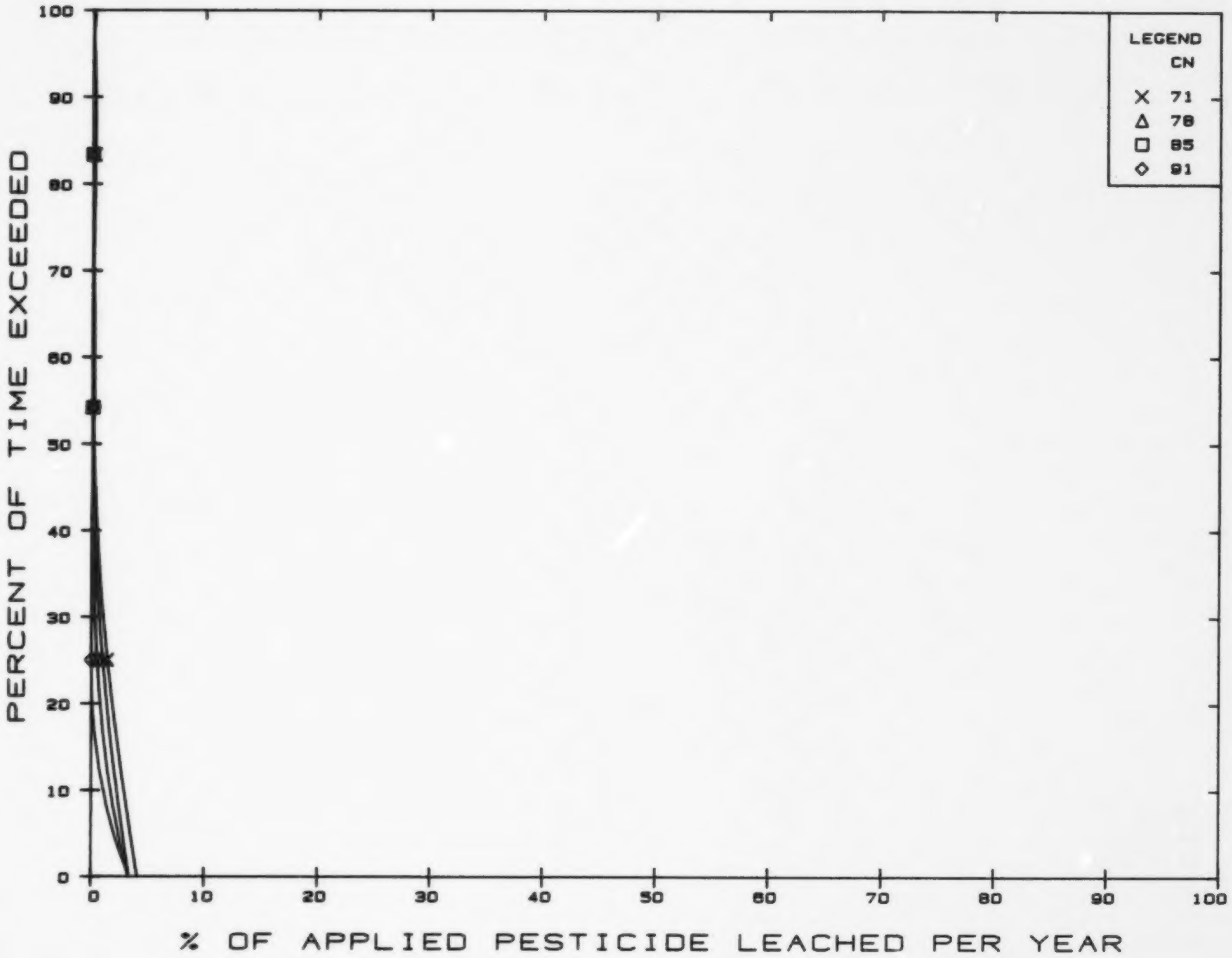


FIGURE A18-15 R=50. KS=.001

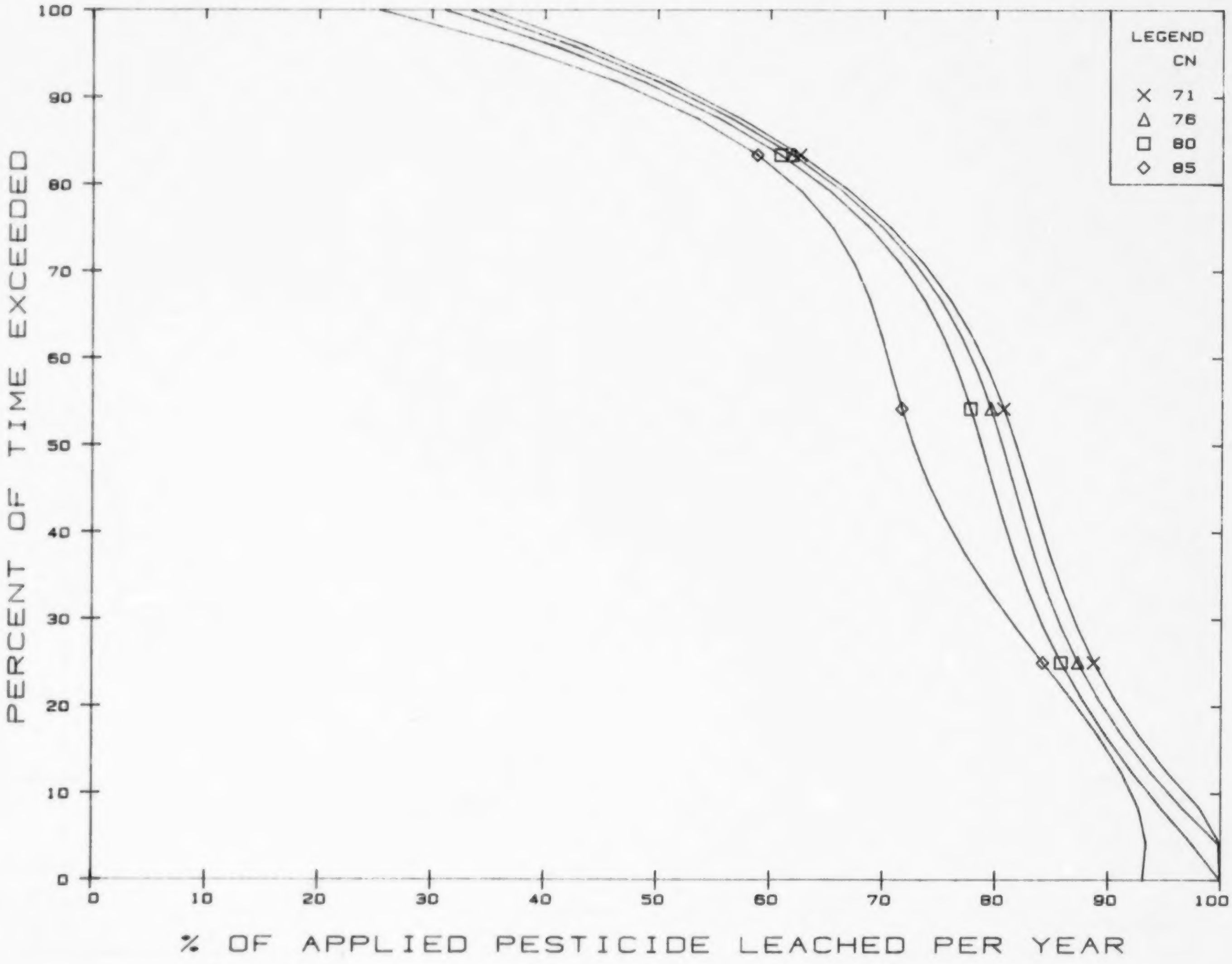


FIGURE A19-1 R=1. KS=.001

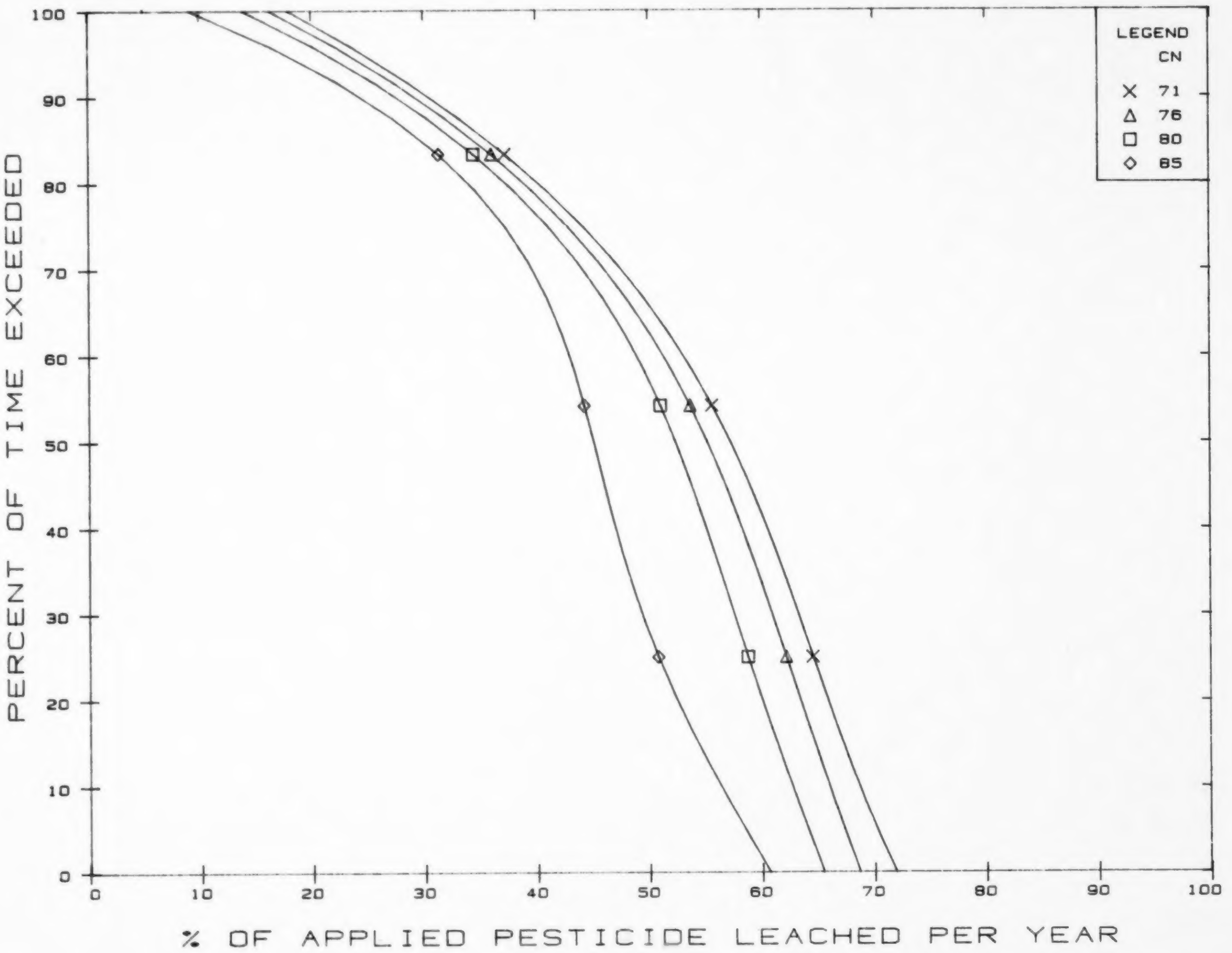


FIGURE A19-2 R=1. KS=.005

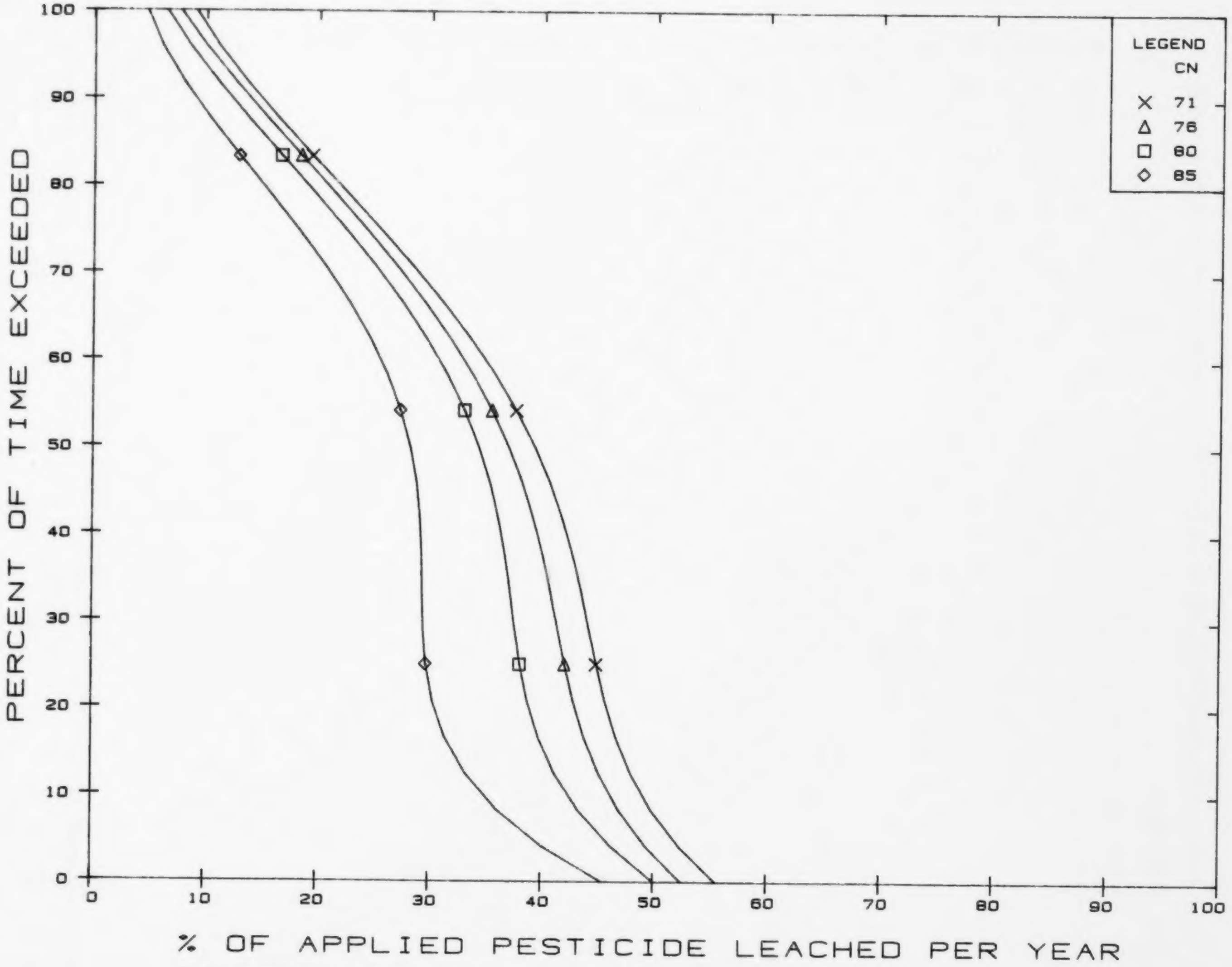


FIGURE A19-3 R=1. KS=.010

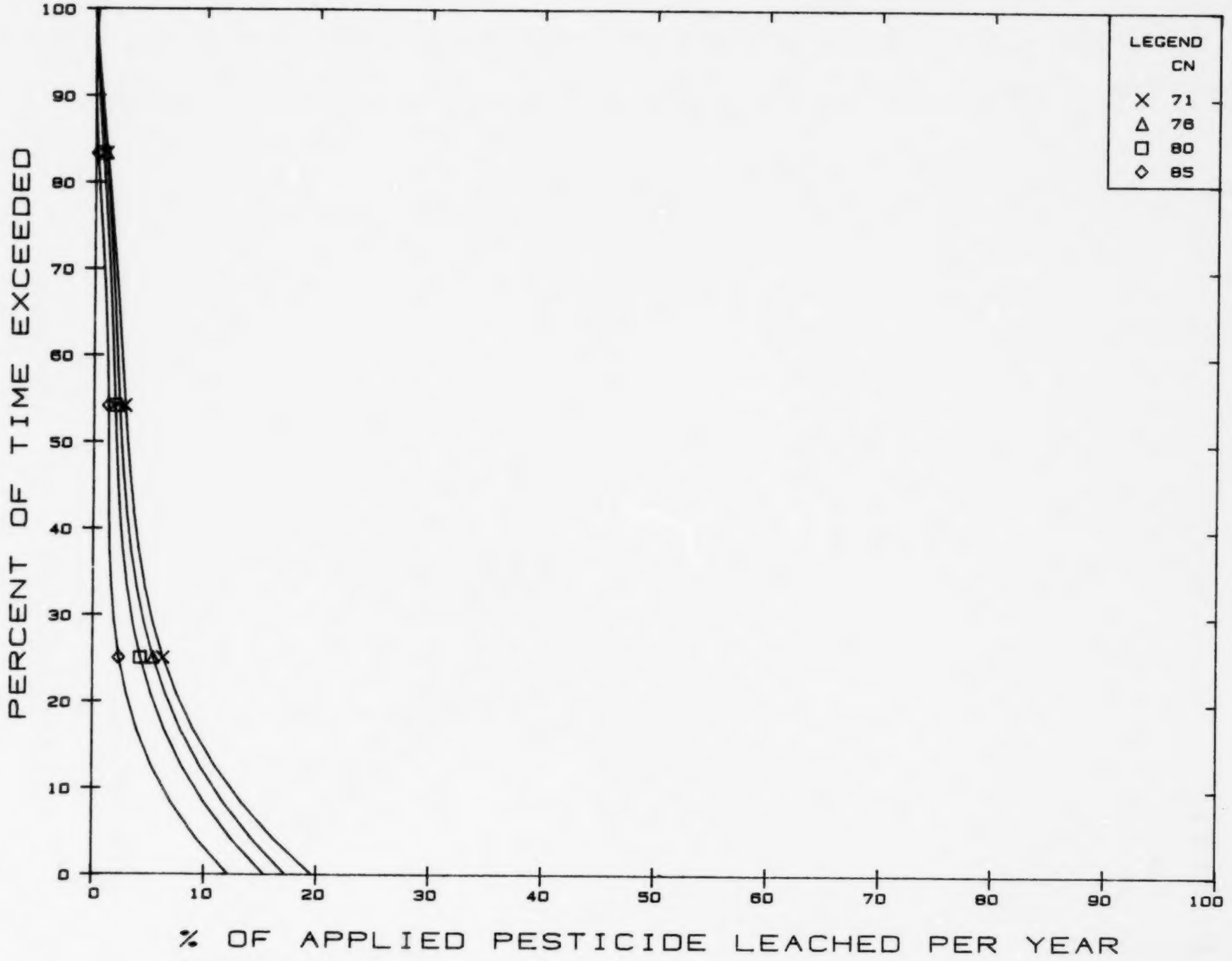


FIGURE A19-4 R=1. KS=.050

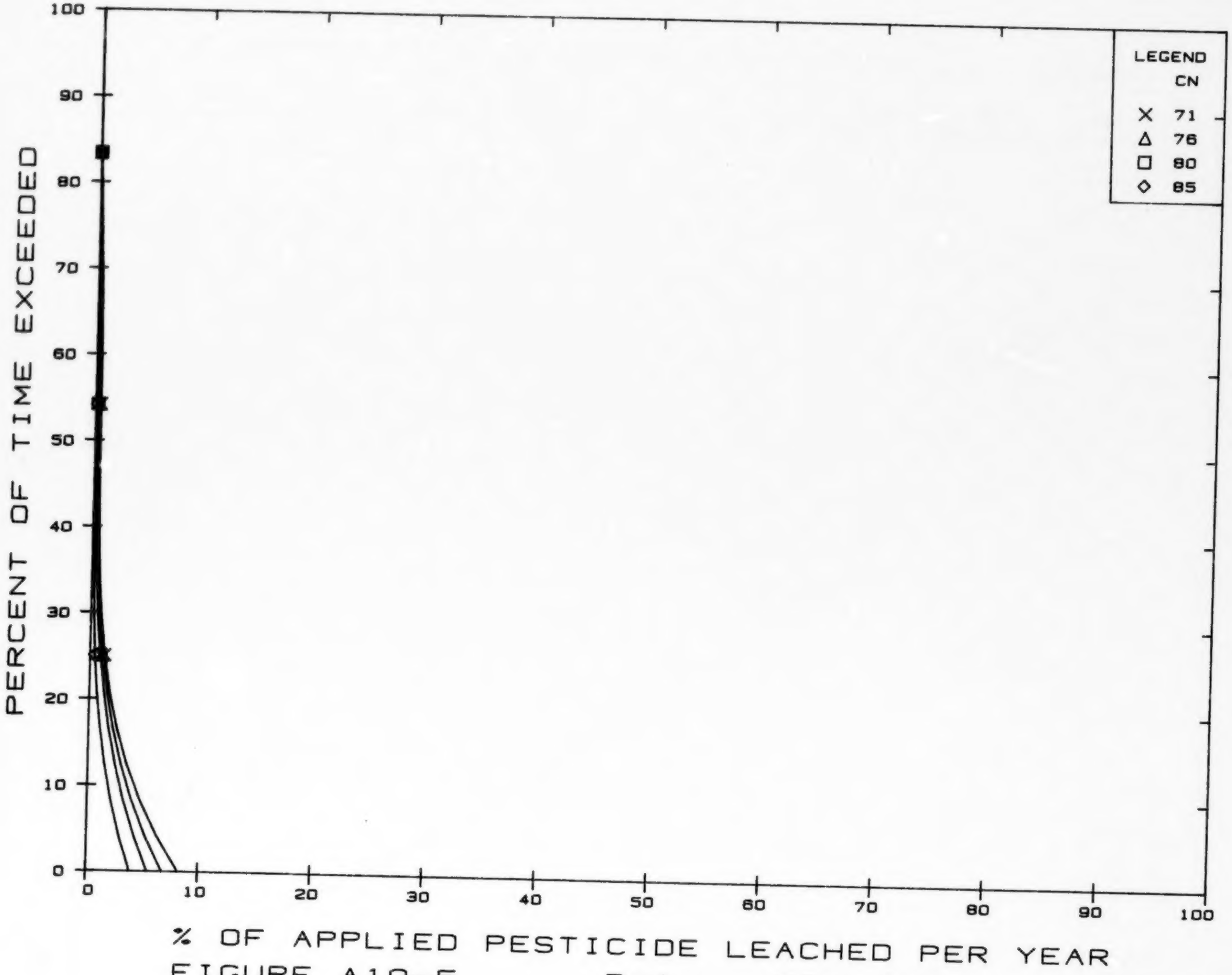


FIGURE A19-5 R=1. KS=.100

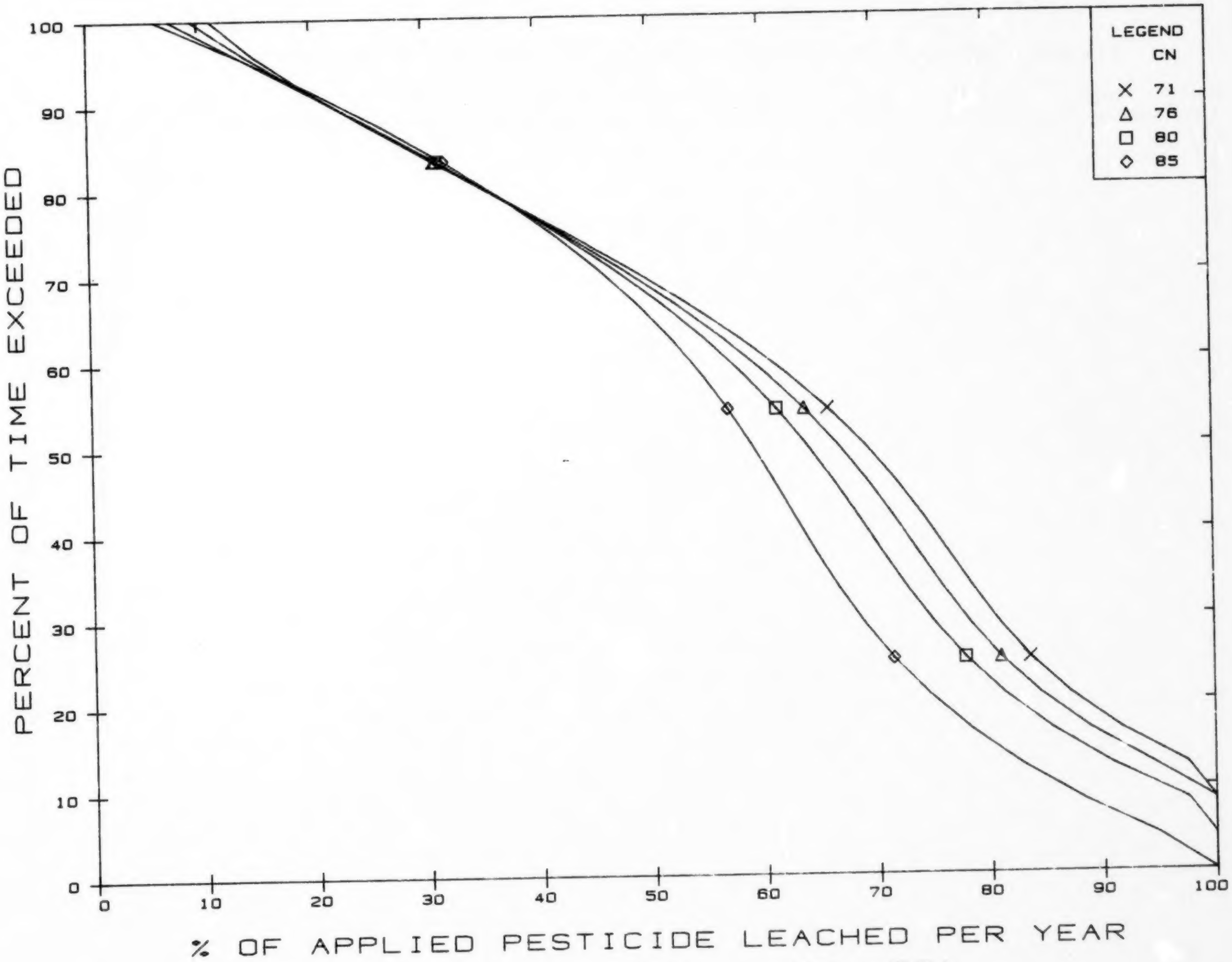


FIGURE A19-6 R=3. KS=.001

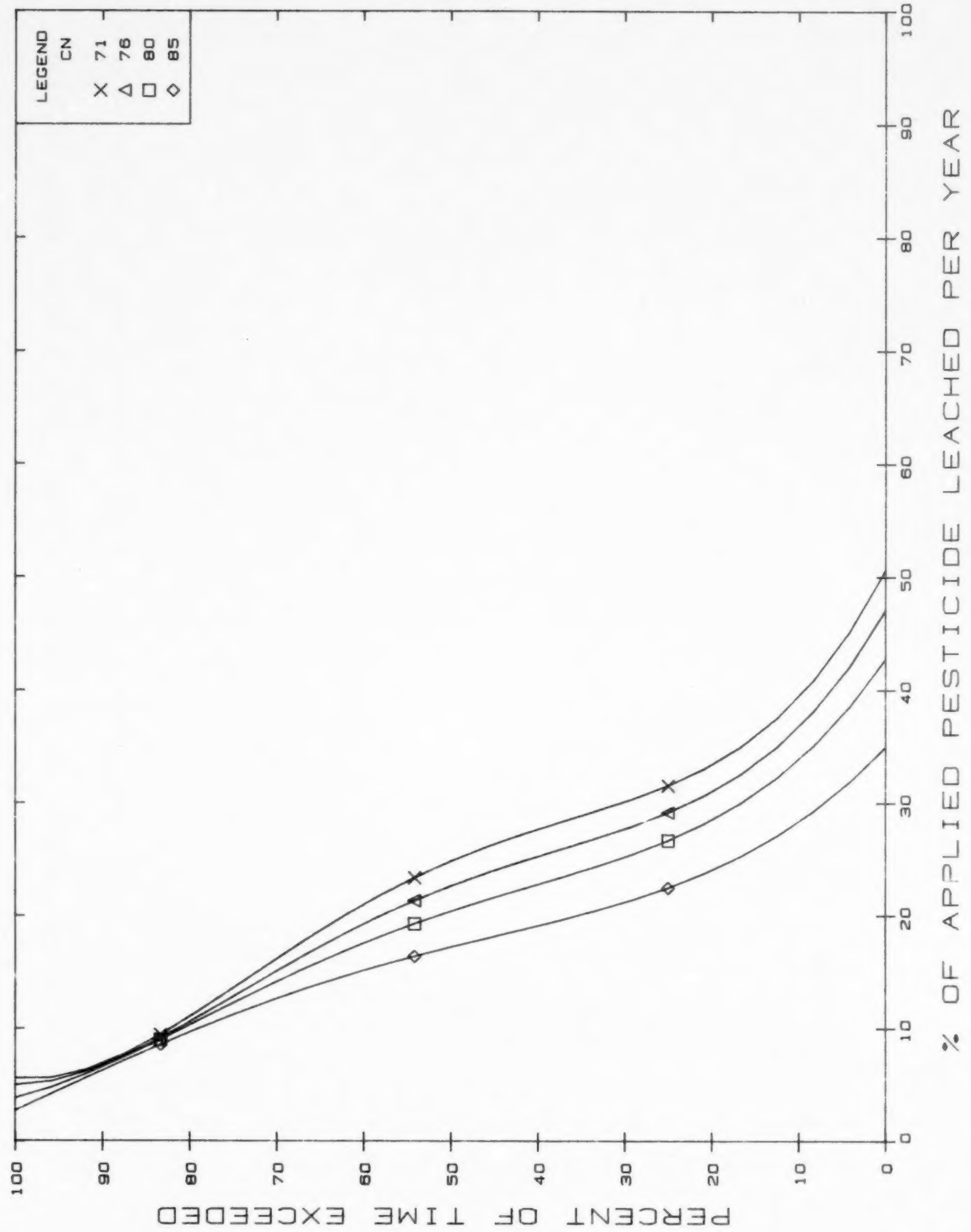


FIGURE A19-7 R=3. KS=.005

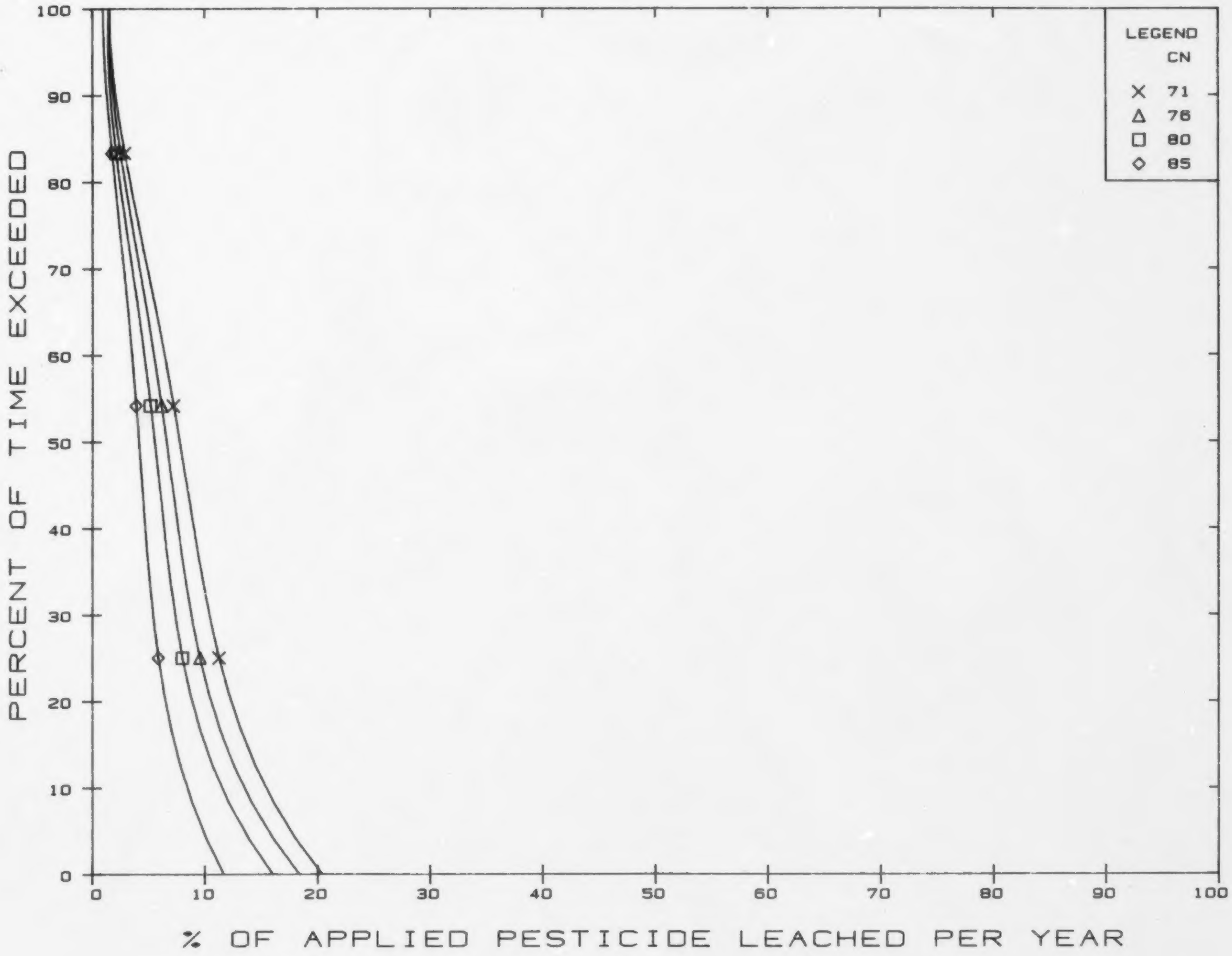


FIGURE A19-8 R=3. KS=.010

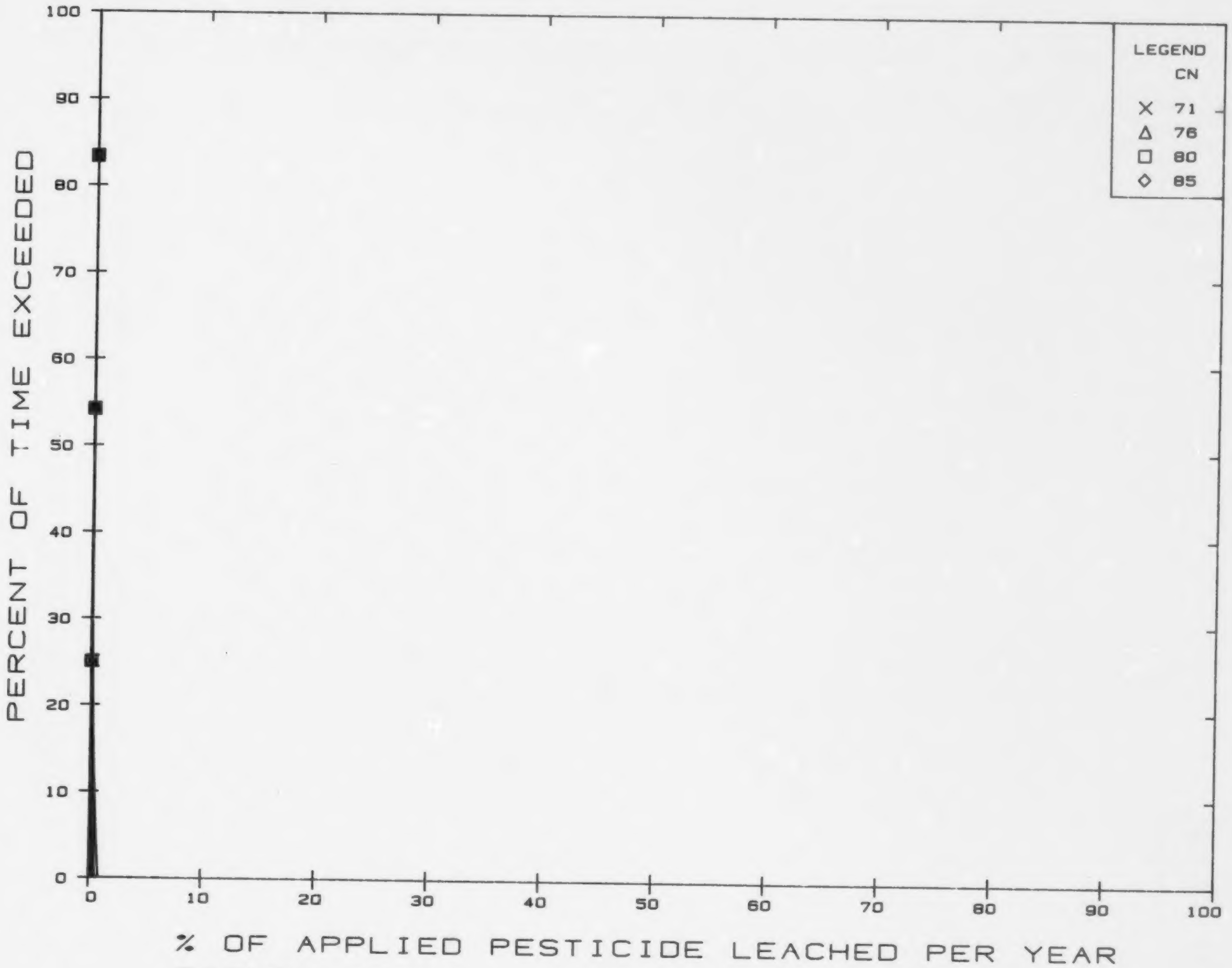


FIGURE A19-9 R=3. KS=.050

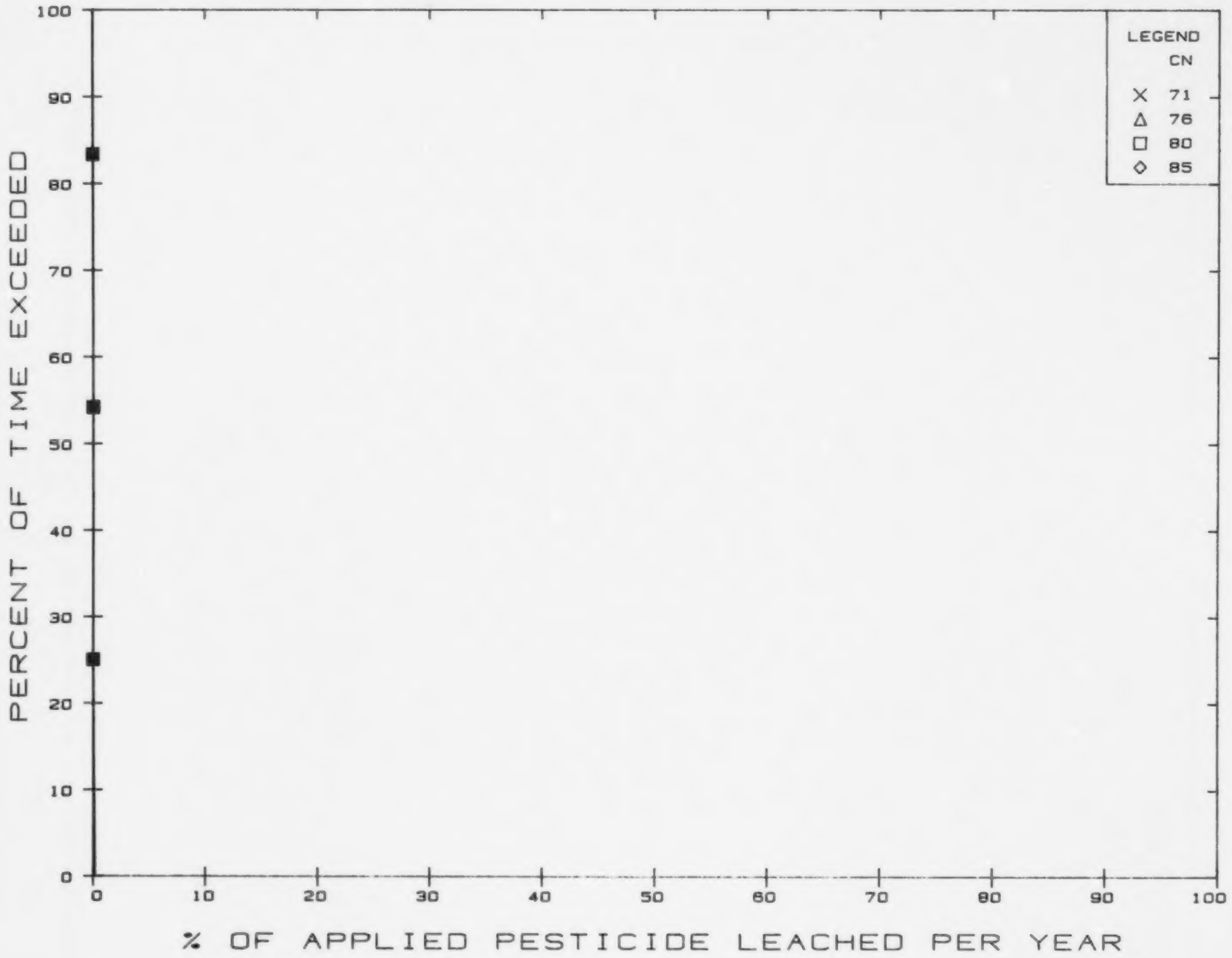


FIGURE A19-10 R=3. KS=.100

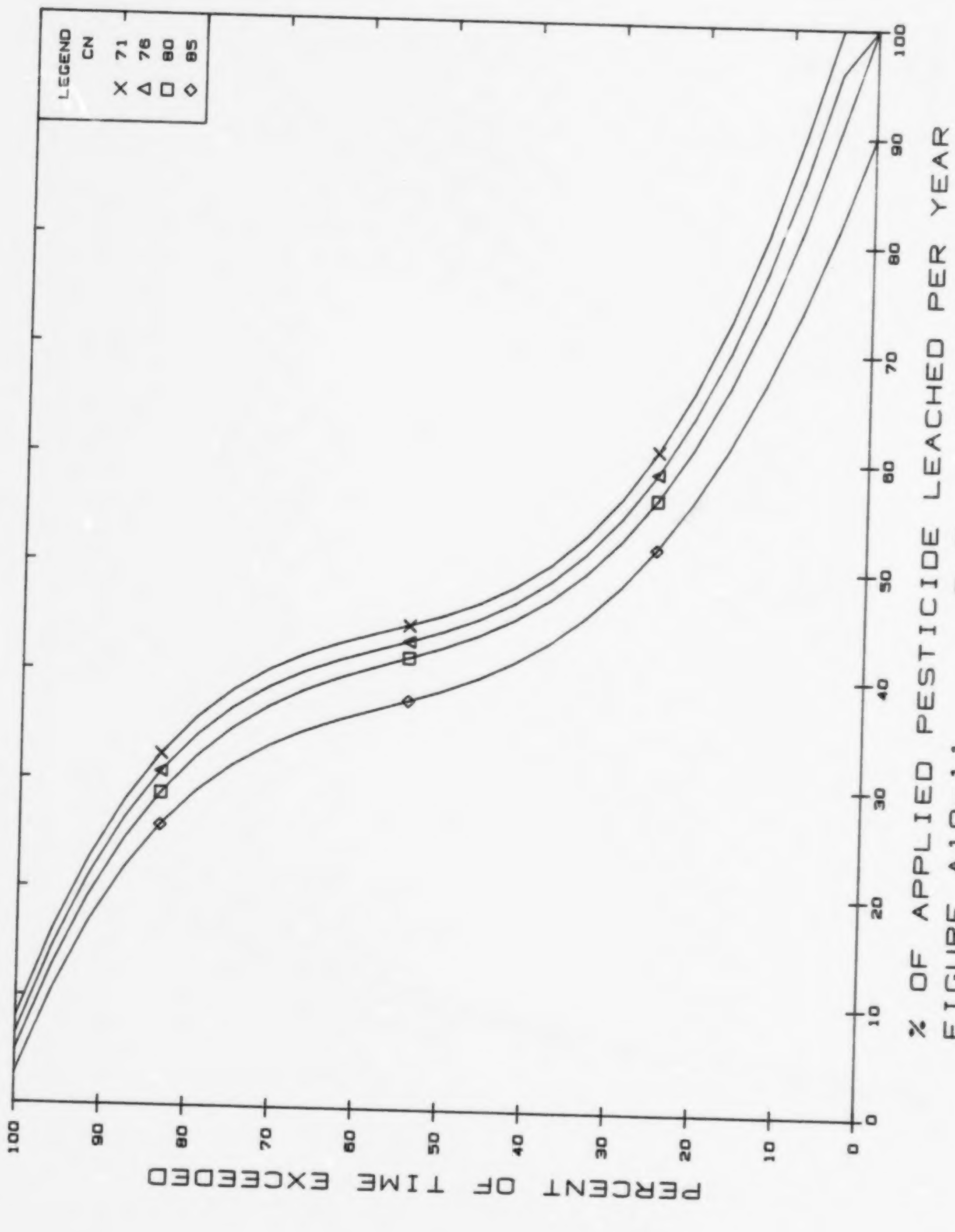


FIGURE A19-11 R=5. KS=.001

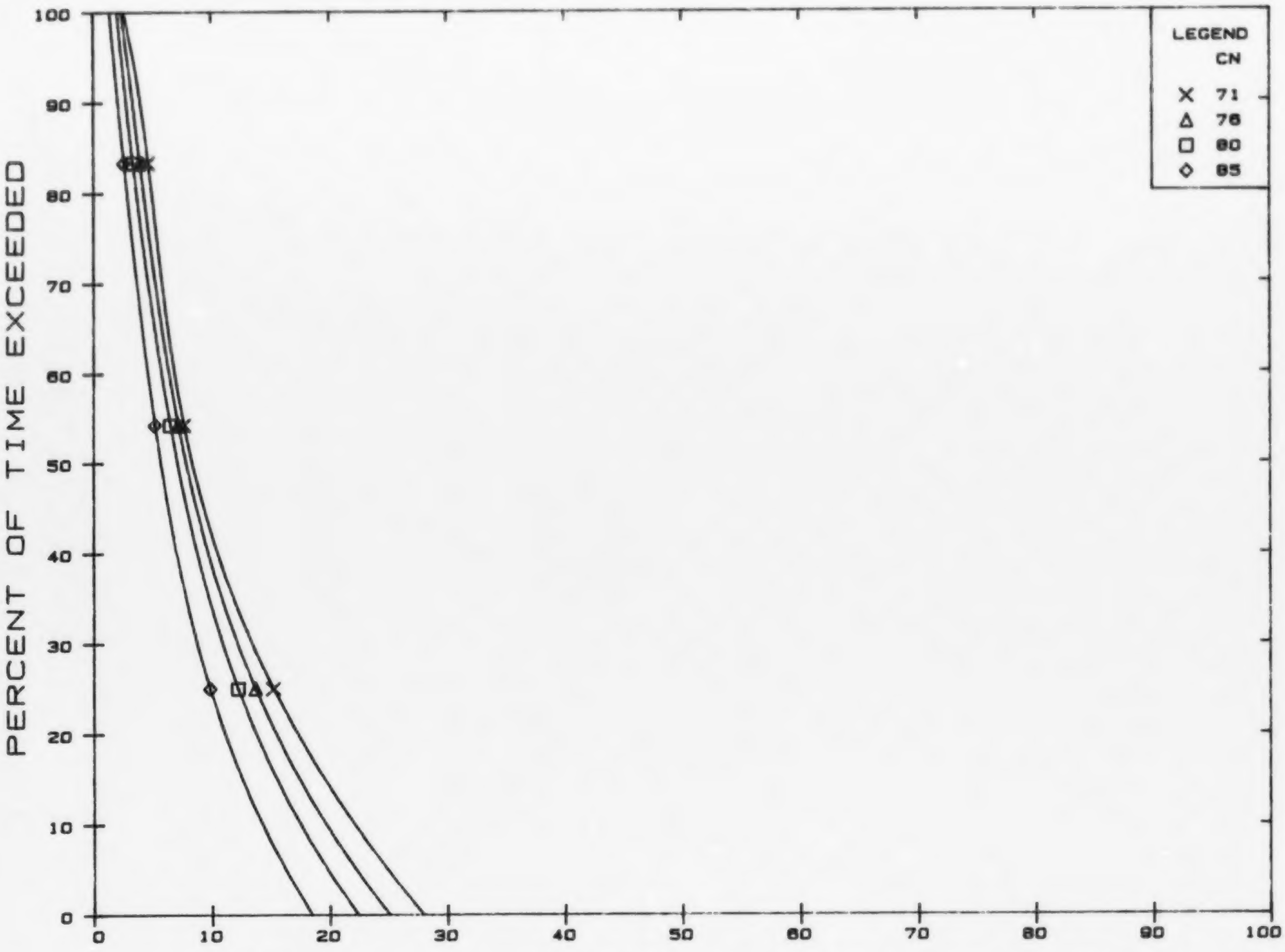


FIGURE A19-12 R=5. KS=.005

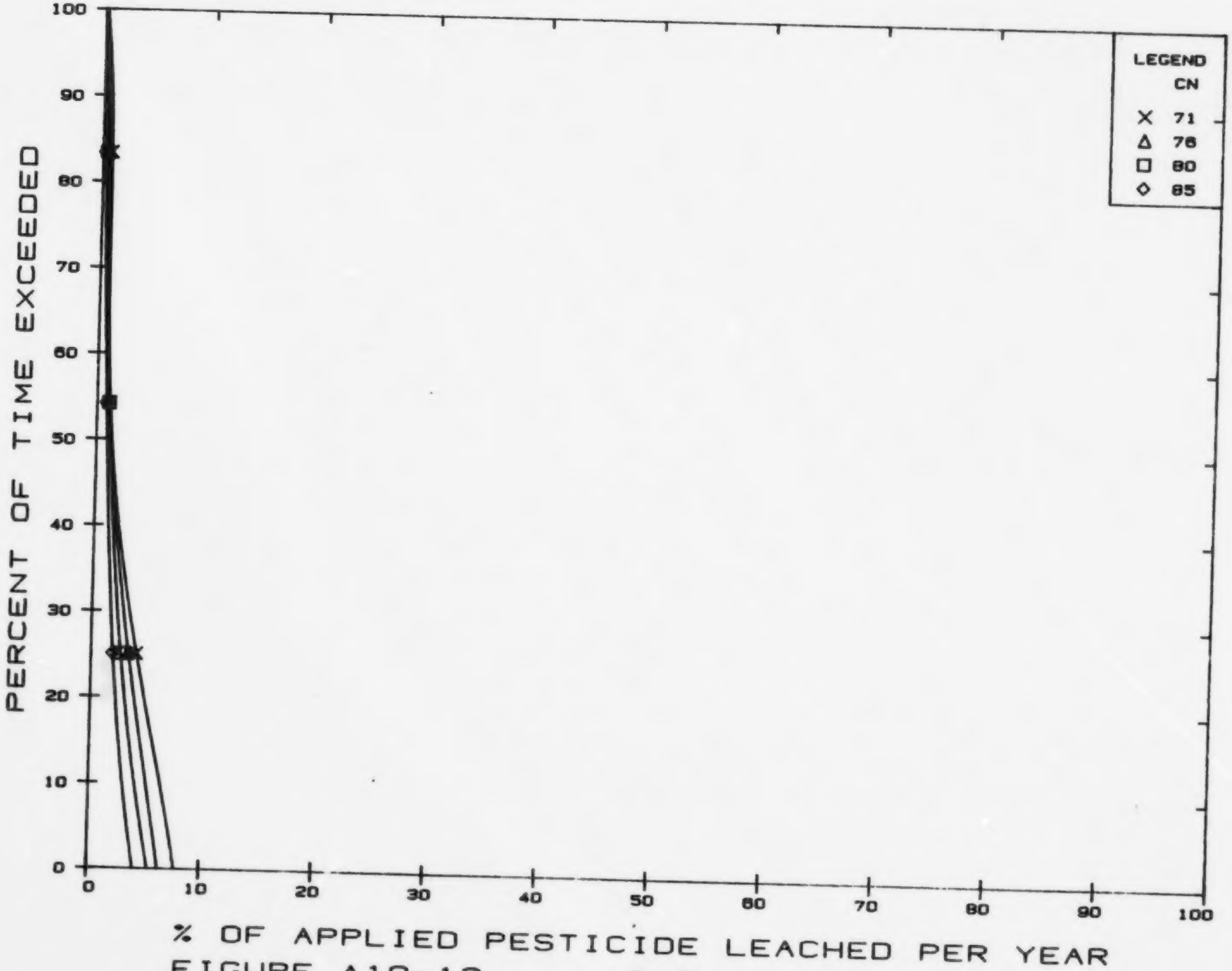


FIGURE A19-13 R=5. KS=.010

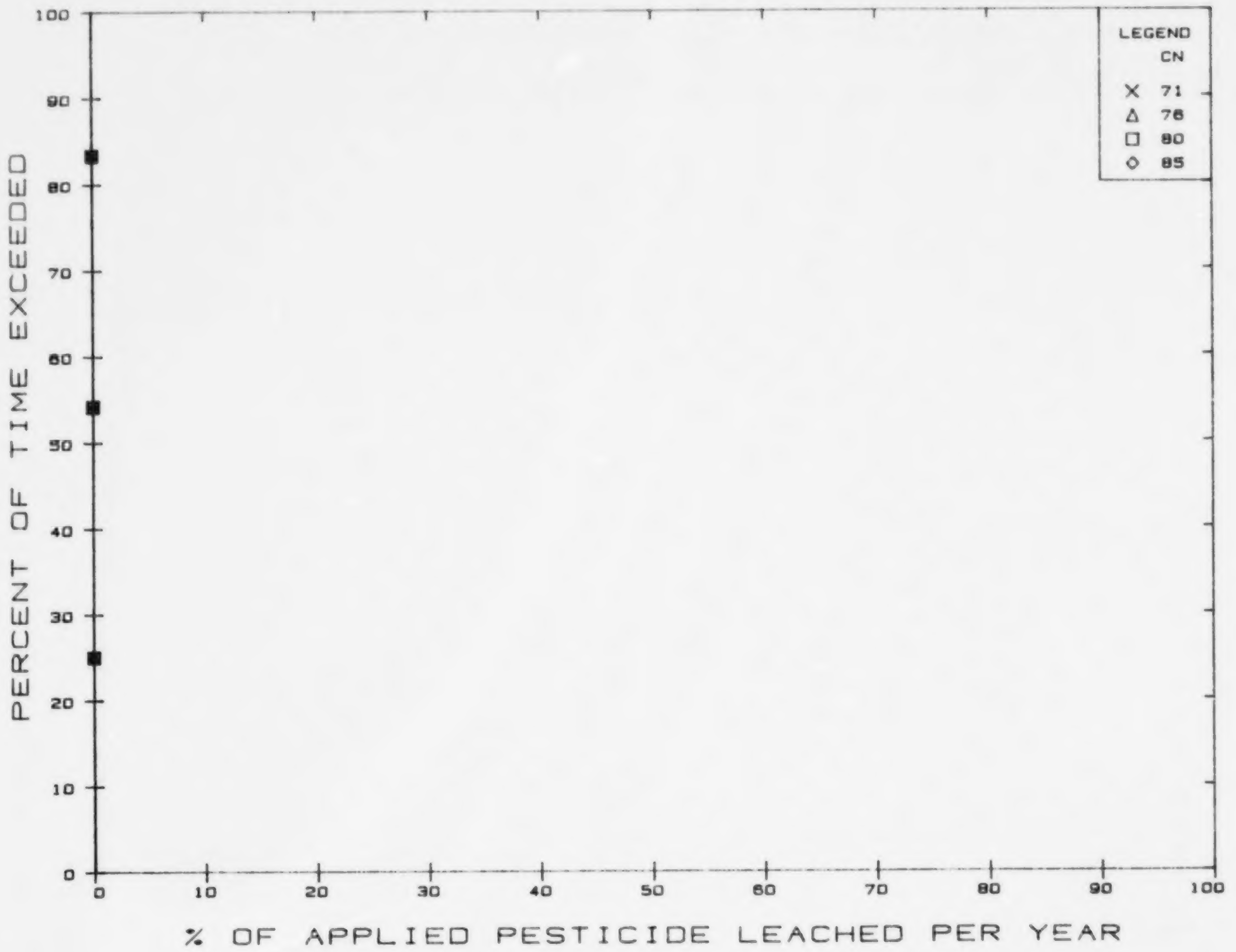


FIGURE A19-14 R=5. KS=.050

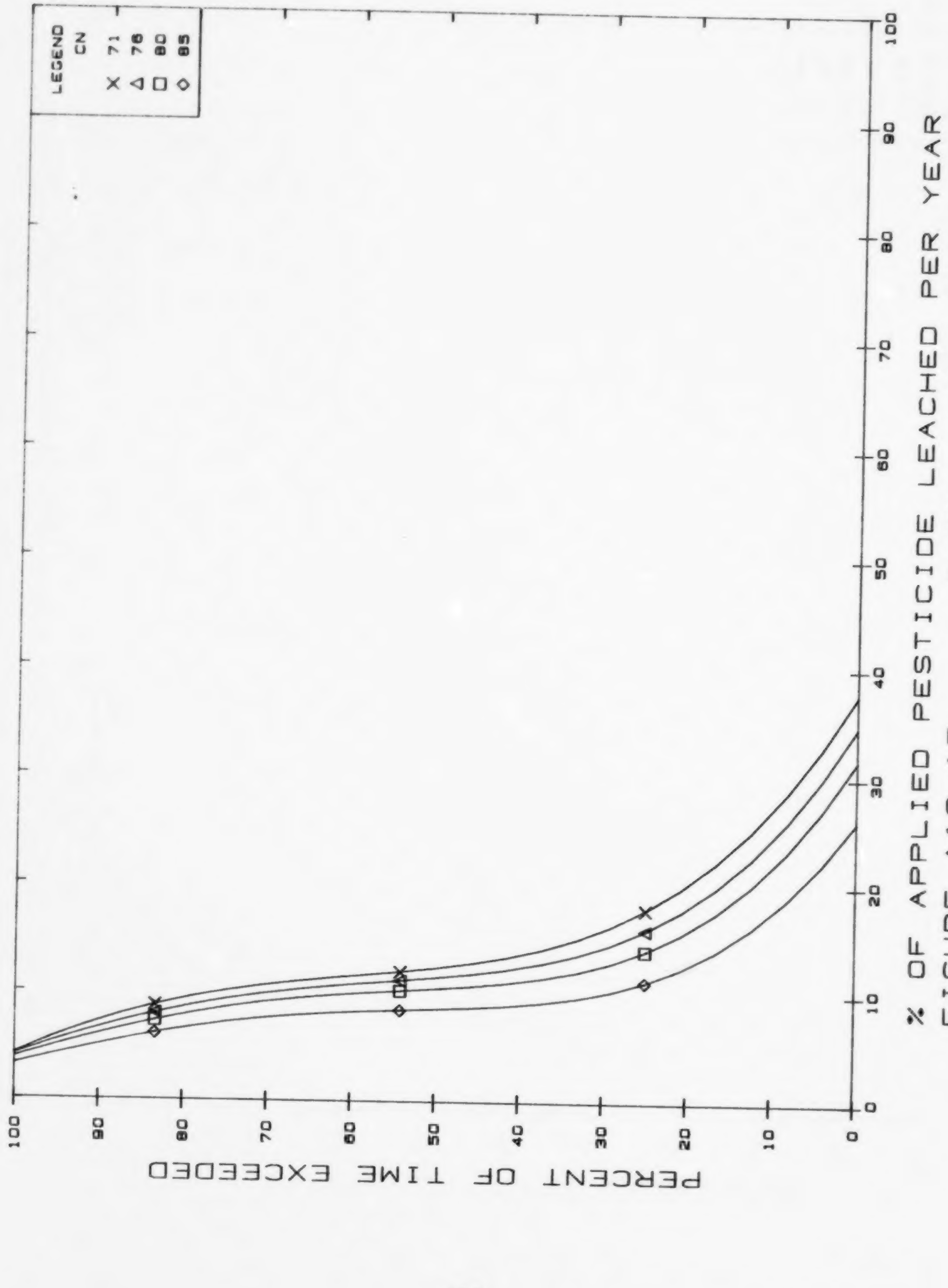


FIGURE A19-15 R=20. KS=.001

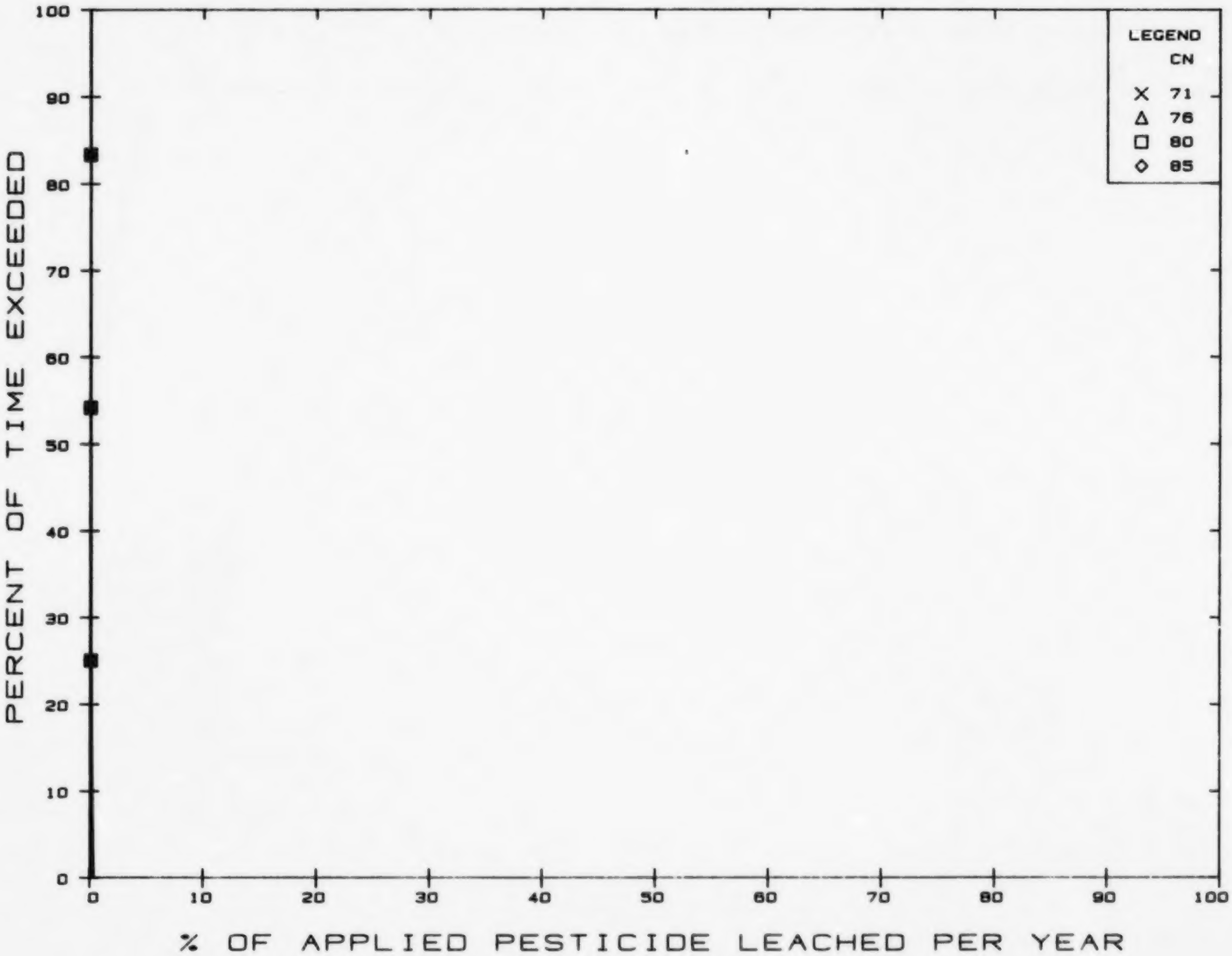


FIGURE A19-16 R=20. KS=.005

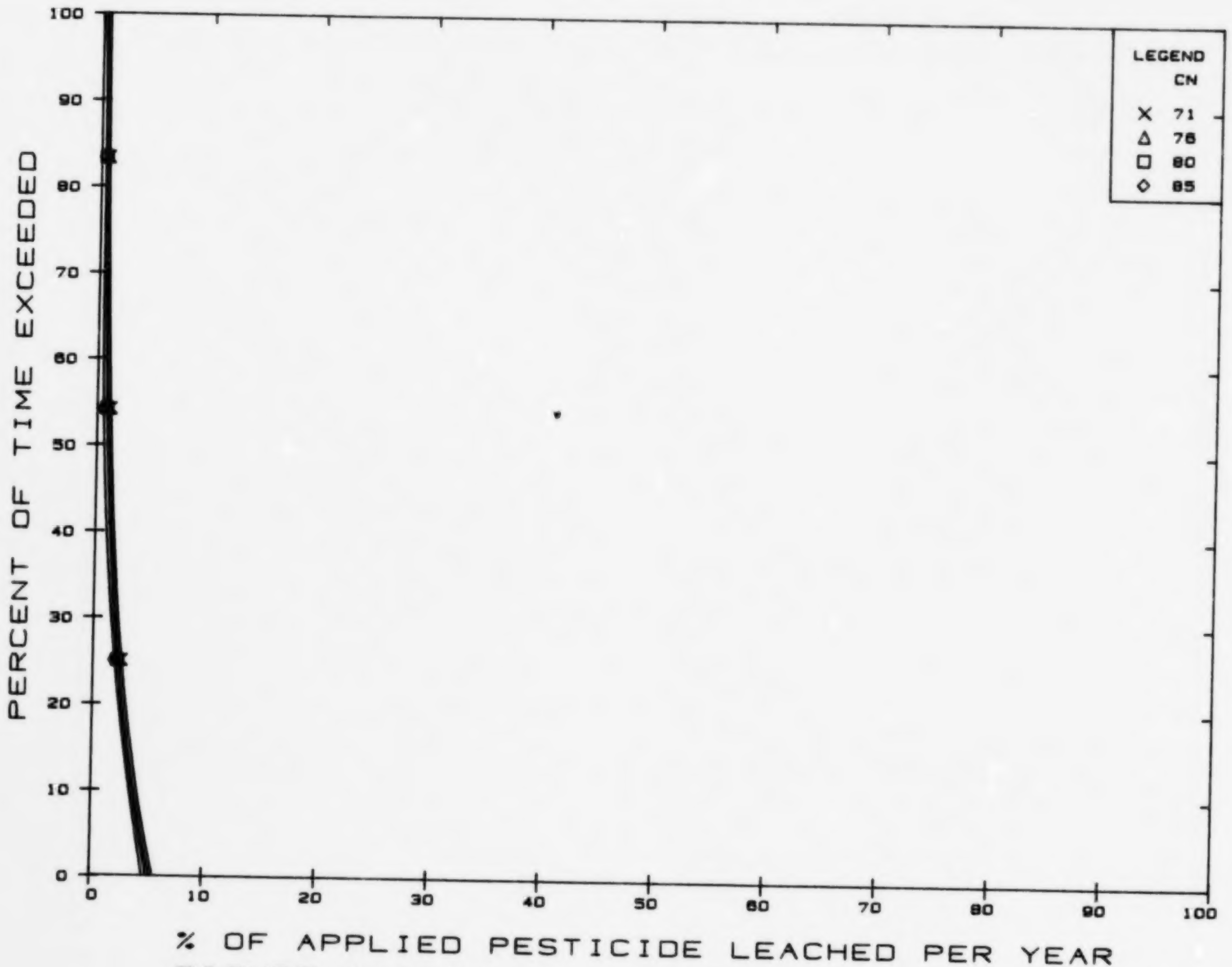


FIGURE A19-17 R=50. KS=.001

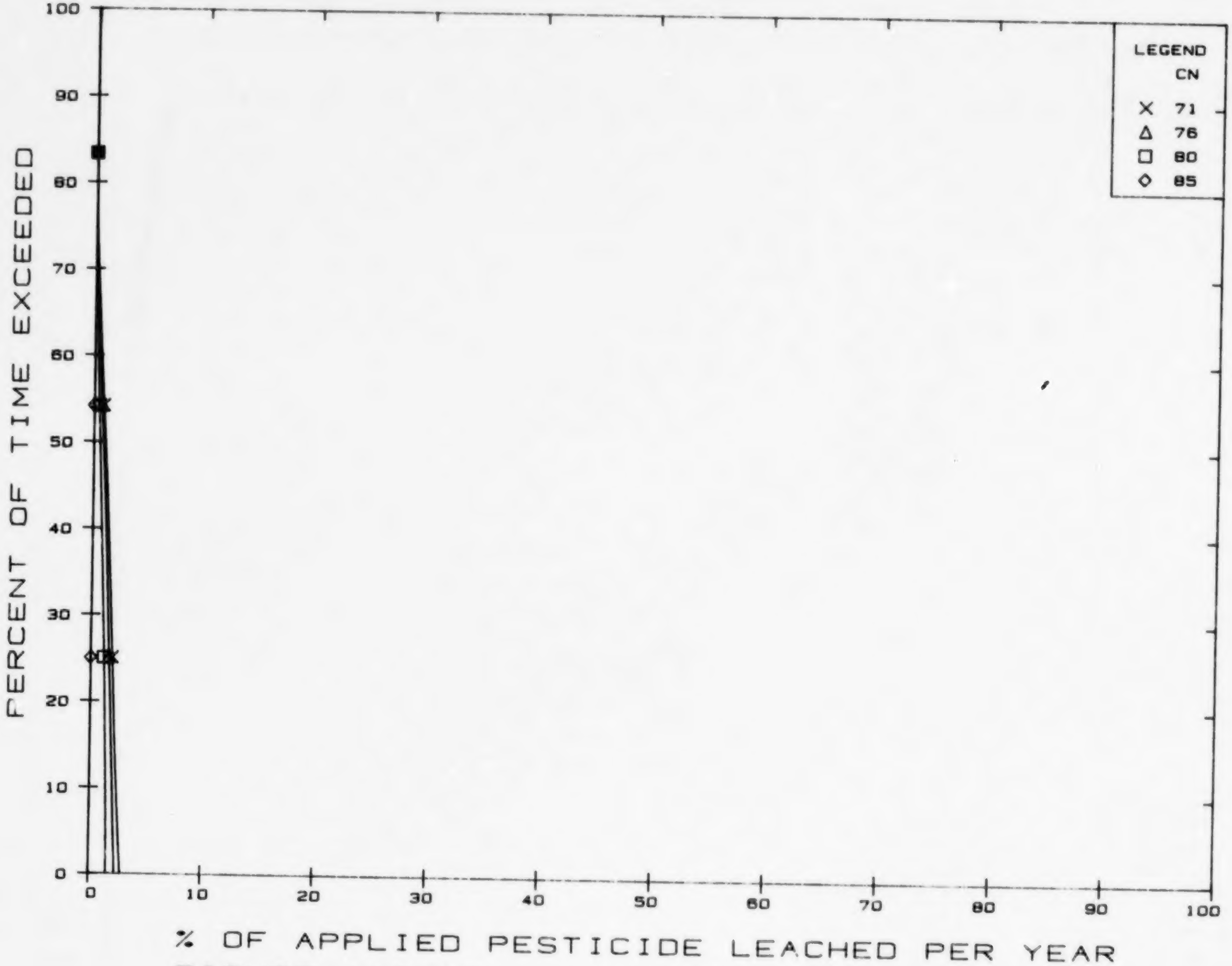


FIGURE A19-18 R=50. KS=.005

APPENDIX B

Supplemental Chemical Data

TABLE B-1. SUMMARY OF ADSORPTION PARTITION COEFFICIENT VALUES COMPILED FROM PUBLISHED LITERATURE FOR SEVERAL PESTICIDES AND RELATED ORGANIC COMPOUNDS

Pesticide	Number of Soils	K_d Mean (%CV)	K_{oc} Mean (%CV)
AMETRYNE	32	6.16(65.1)	388.4(57.1)
AMIBEN	12	1.40(145.2)	189.6(149.7)
ATRAZINE	56	3.20(89.8)	163.0(49.1)
BROMACIL	2		72.0 (102.1)
CARBOFURAN	5	1.05(111.8)	29.4(30.0)
CHLOROBROMURON	5	37.22(121.2)	995.6(55.1)
CHLORONEB	1		1652.9(--)
CHLOROXURON	5	234.0(71.1)	4343.3(28.8)
CHLOROPROPHAM	36		816.3(--)
CHLORTHIAMID	6	5.57(39.7)	98.3(27.5)
CIODRIN	3		74.8(59.1)
DDT	2		243118.0(65.0)
DICAMBA	5	0.11(103.9)	2.2(73.5)
DICHLOBENIL	34	3.0(70.9)	224.4(77.4)
DIMETHYL AMINE	5	14.0(77.3)	434.9(19.8)
DIPROPETRYNE	5	13.5(91.5)	1180.8(74.9)
DISULFOTON	20	32.3(91.7)	1603.0(144.2)
DIURON	84	8.9(150.8)	382.6(72.4)
FENURON	10	2.11(120.8)	42.2(84.7)
LINDANE	3	20.1(13.5)	1080.9(13.0)
LINURON	33	21.2(100.2)	862.8(72.3)

(continued)

TABLE B-1 (continued)

Pesticide	Number of Soils	K_d Mean (% CV)	K_{oc} Mean (% CV)
MALATHION	20	34.1(67.1)	1796.9(65.9)
METHYL PARATHION	7	12.7(67.2)	5101.5(113.6)
METHYL UREA	5	3.5(80.1)	58.8(15.1)
METOBROMURON	4	6.7(62.8)	271.5(37.1)
MONOLINURON	10	12.3(83.6)	284.3(55.2)
MONURON	18	7.6(122.5)	183.5(60.8)
NEBURON	5	166.8(68.3)	3110.5(23.5)
p-CHLOROANILINE	5	16.8(79.4)	561.5(33.6)
PARATHION	4	21.9(63.7)	10650.3(74.6)
PHENYL UREA	5	4.9(91.9)	76.3(12.3)
PICLORAM	26	0.63(150.2)	25.5(138.5)
PROMETONE	29	7.2(147.5)	524.3(143.6)
PROMETRYNE	38	10.8(123.8)	614.3(99.1)
PROPAZINE	36	3.1(135.8)	153.5(37.0)
SIMAZINE	147	2.3(158.5)	138.4(12.6)
TELONE (cis)	6	54.8(78.6)	798.1(44.3)
TELONE (trans)	6	93.2(72.0)	1379.0(45.4)
TERBACIL	4	0.78(145.0)	41.2(42.2)
THIMET	4	8.8(77.7)	3255.2(49.5)
TRITHION	4	74.6(26.6)	46579.7(80.2)
2,4-D	9	0.78(128.6)	19.6(72.4)
2,2-D AMINE	3	2.0(112.5)	109.1(30.2)
2,4,5-T	4	1.6(87.3)	80.1(45.3)

Source: Rao and Davidson, 1980

TABLE B-2. MEASURED VALUES OF K_{oc} FOR SELECTED CHEMICALS

Chemical	K_{oc} Mean (% CV)
Dicamba	2.2(74)
2,4-D	20(72)
Picloram	26(140)
Carbofuran	29(30)
Acetophenone	43
Ethylene dibromide	44
Benzene	83
Chlorthiamid	98(28)
Simazine	140(13)
Atrazine	160(49)
Fluometrom	175
Carboryl	230
p-Cresol	<500
Quinoline	570
Linuron	860(72)
Nitralin	960
Lindane	1,080(13)
Disulfoton	1,600(140)
Malathion	1,800(66)
Diallate	1,900
Neburon	3,100(24)
Hexachlorobenzene	3,900
Parathion	10,600(75)
Dibenzothiophene	11,200
Trifluralin	13,700
2,2',4,5,5'-Pentachlorobiphenyl	42,500
Methoxychlor	80,000
DDT	243,000(65)
7,12-Dimethylbenz[a]anthracene	476,000
Benz[a]anthracene	1,380,000
Mirex	24,000,000

Values given are often the mean of measurements on a variety of soils and/or sediments. All values may be assumed to be uncertain by at least 10%. Units of K_{oc} are cm**3/gram. In several cases the values of K_{oc} have been rounded off from those given in the original references.

% CV = % Coefficient of variation = (standard deviation/mean) x 100. Unlisted values are not available.

Source: Lyman, et al., 1982

TABLE B-3. SUMMARY OF OCTANOL-WATER PARTITION COEFFICIENTS (K_{ow}) FOR PESTICIDES COMPILED FROM LITERATURE-I

Pesticide	K_{ow}	Pesticide	K_{ow}
A. INSECTICIDES		PROPOXUR	2.80000E+01
		RONNEL	7.58580E+04
ALDICARB	5.00000E+00	TERBUFOS	1.67000E+02
ALTOSID	1.76000E+02	TOXAPHENE	1.69500E+03
CARBARYL	6.51000E+02		
CARBOFURAN	2.07000E+02	B. HERBICIDES	
CHLORDANE	2.10800E+03		
CHLORPYRIFOS	2.05900E+03	ALACHLOR	4.34000E+02
CHLORPYRIFOS	6.60000E+04	ATRAZINE	2.12000E+02
CHLORPYRIFOS	1.28825E+05	ATRAZINE	2.26000E+02
CHLORPYRIFOS, METHYL	1.97000E+03	BIFENOX	1.74000E+02
CHLORPYRIFOS, METHYL	2.04170E+04	BROMACIL	1.04000E+02
DDD	1.15000E+05	CHLORAMBEN	1.30000E+01
DDE	7.34450E+04	CHLOROPROPHAM	1.16000E+03
DDE p,p	4.89779E+05	DALAPON	5.70000E+00
DDT	3.70000E+05	DALAPON, NA SALT	1.00000E+00
DDT p,p	1.54882E+06	DICAMBA	3.00000E+00
DDVP	1.95000E+02	DICHLOBENIL	7.87000E+02
DIALIFOR	4.89780E+04	DIURON	6.50000E+02
DIAZINON	1.05200E+03	MONURON	1.33000E+02
DICHLOFENTHION	1.38038E+05	MSMA	8.00000E-04
DICIFOL	3.46100E+03	NITROFEN	1.24500E+03
DIELDRIN	4.93000E+03	PARAQUAT .2HCL	1.00000E+00
DINOSEB	1.98000E+02	PICLORAM	2.00000E+00
ENDRIN	1.61900E+03	PROPACHLOR	4.10000E+01
ETHOXYCHLOR	1.18000E+03	PROPANIL	1.06000E+02
FENITROTHION	2.29900E+03	SIMAZINE	8.80000E+01
HCB	1.66000E+06	TERBACIL	7.80000E+01
HEPTACHLOR	7.36600E+03	TRIFLURALIN	1.15000E+03
LEPTOFOS	4.12200E+03	2,4-D	4.16000E+02
LEPTOPHOS	2.04174E+06	2,4-D	4.43000E+02
LINDANE	6.43000E+02	2,4-D	6.46000E+02
MALATHION	2.30000E+02	2,4,5-T	7.00000E+00
MALATHION	7.76000E+02	2,4,5-T, BUTYL ESTER	6.40000E+04
METHOMYL	1.20000E+01	2,4,5-T OCTYL ESTER	9.09000E+02
METHOXYCHLOR	2.05000E+03		
METHOXYCHLOR	1.20000E+05	C. FUNGICIDES	
METHYL PARATHION	2.07600E+03		
PARATHION	6.45500E+03	BENOMYL	2.64000E+02
PERMETHRIN	7.53000E+02	CAPTAN	3.30000E+01
PHORATE	8.23000E+02	PCP	1.42900E+04
PHOSALONE	1.99530E+04		
PHOSMET	6.76000E+02		

Source: Rao and Davidson, 1980

TABLE B-4. SUMMARY OF OCTANOL-WATER PARTITION COEFFICIENTS (K_{ow}) FOR PESTICIDES COMPILED FROM THE LITERATURE-II

Compound	Observed K_{ow}
Methylacetylene	8.71
Fluoroform	4.37
Isobutylene	218.8
Ethanol	0.49
Dimethyl ether	1.26
Cyclohexane	2754.0
Propane	229.1
2-Propanol	1.12
tert-Butylamine	2.51
2-Phenylethylamine	25.7
N-Phenylacetamide	14.5
Halothane	199.5
Benzimidazole	21.9
ρ-Nitrophenol	81.3
Cyclohexene	724.4
1,2-Dichlorotetrafluoroethane	660.7
Hexachlorophene	8511.0
1,2-Methylenedioxybenzene	120.2
2-Phenyl-1,3-indandione	794.3
Carbon tetrachloride	676.1
Dioxane	0.38
2-Bromoacetic acid	2.57
2-Chloroethanol	1.07
Indene	831.8
Fluorene	13183.0
Anthracene	28184.0
Pyrene	75858.0
Quinoxaline	12.0
Carbozole	3236.0
Menadione	158.5
Chloramphenicol	13.8
2-Hydroxy-1,4-naphthoquinone	28.8
2-Methyl-3-hydroxyl-1,4-naphthoquinone	15.8
2-Methoxy-1,4-naphthoquinone	22.4
Benzothiazole	102.3
o-Phenanthroline	67.6
Thiazole	2.75
Piperazine	0.07
Morpholine	0.08
Salicylic acid	173.8

(continued)

TABLE B-4 (continued

Compound	Observed K_{ow}
Imidazole	0.83
Cylcohexanol	17.0
o-Phenyleneurea	13.2
Tripropylamine	616.6
Di-*n*-propylamine	41.7
Coumarin	24.5
Trifluoromethylbenzene	794.3
Trifluoromethylsulfonanilide	1122.0
1,3-Indandione	4.07
9-Fluorenone	3802.0
Phenazine	691.8
Morphine	6.76
2,2,2-Trifluoroethanol	2.57
2,2,2-Trifluoroacetamide	1.32
2,2,2-Trichloroethanol	22.4
2,2,2-Trichloroacetamide	11.0
Pyrimidine	0.40
Glucose	0.001
Cyclohexylamine	30.9
Neopentane	1288.0
2-Methylpropane	575.4
Crotonic acid	5.25
Cinnamonitrile	91.2
Cinnamic acid	134.9
Cinnamamide	25.7
Methyl cinnamate	416.9
Phenyl vinyl ketone	75.9
Styrene	891.3
1-Phenyl-3-hydroxypropane	89.1
Methyl styryl ketone	117.5
1,1,2-Trichloroethylene	195.0
2-Methoxyanisole	120.2
Ethyl vinyl ether	11.0
Pyrazole	1.35
1,1-Difluoroethylene	17.4
1,2,3,4-Tetrahydroquinoline	195.0

Source: Lyman, et al., 1982

TABLE B-5. VALUES OF K_s FOR DISSIPATION OF PESTICIDES FROM SOIL SURFACES

Pesticide	k_s	Pesticide	k_s
HERBICIDES		INSECTICIDES	
Alulam	0.0141	Aldrin	0.2406
	.1174	Aldrin	
Benefin	.3349	(+dieldrin)	.0045
Butralin	.1077	(granules)	
2,4-D isooctyl	.0923	Azinphosmethyl	.0486
2,4-D isooctyl	.0183	(spray)	
2,4-D	.0788	Azinphosmethyl	.0434
2,4-D isooctyl	.0486	(spray)	
2,4-D amine	.0522	Carbofuran	.0075
2,4-D amine	.0139	Carbofuran	.0690
2,4-D amine	.0108	Carbofuran	.0180
2,4-D	.1634	Carbofuran	.0048
2,4-D	.1036	Carbofuran	.034
2,4-D amine	.0352	Carbofuran	.086
2,4-D isooctyl	.2603	Carbofuran	.0040
Dicamba	.0151	Carbofuran	.0059
Diflubenzuron	.0040	Carbofuran	.0132
Dinitramine	.0856	Chlordane	.0101
Diuron	.136	Chlordane	.007
Diuron	.214	DDT	.004
Fluchloralin	.0169	DDT	.053
Fluometuron	.043	DDT	.0060
Fluometuron	.077	DDT	.0049
Isopropalin	.1948	DDT	.0060
Nitralin	.1042	DDT	.00015
Oryzalin	.0284	DDT	.000023
Oxmyl	.0646	DDT	.00040
Oxmyl	.0354	DDT	.00014
Oxmyl	.0448	DDT	.00024
Pendimethalin	.1695	DDT	.00044
Picloram	.2689	Diazinon	.1422
Picloram	.0712	Endrin	.0110
Profluralin	.2434	Endrin	.2436
Prometryne	.0127	Ethion	.0647
Pronamide	.0203	Ethion	.0702
	.0603	Ethyl	
Pronamide	.0173	parathion	.0332
Propham	.025	Ethyl	
Propham	.279	parathion	.0328
Silvex (spray)	.0213	Ethyl	
Silvex (granules)	.0346	parathion	.0282
Simazine	.0089		

(continued)

TABLE B-5 (continued)

Pesticide	k_s	Pesticide	k_s
HERBICIDES		INSECTICIDES	
2,4,5-T (isooctyl)	0.0266	Hexachlorobenzene	0.050
	.075	Methyl parathion	.0165
2,4,5-T	.0674	Methyl parathion	.0153
2,4,5-T	.1323	Methyl parathion	.0147
Trifluralin	.0748	Parathion	.0058
	.0681	Toxaphene	.0046
Trifluralin	.0299		
Trifluralin	.0599		
Trifluralin	.1729		
Trifluralin	.0071		
Trifluralin	.0956		

Source: Nash, 1980

TABLE B-6. VALUES OF K_s FOR DISSIPATION OF PESTICIDES IN SOIL

Pesticide	k_s	Pesticide	k_s
		HERBICIDES	
Alachlor	0.0384	2,4-D isooctyl ester α amine	0.0951
Amitrole	.0768	2,4-D isooctyl ester α amine	.0555
Arsenic acid	<.0064	2,4-D isooctyl ester α amine	.0852
Asulam	.0986	2,4-D isooctyl ester α amine	.0257
Asulam	.0519	Dichlorprop	.0578
Asulam	.0310	Dichlorprop	.0866
Atrazine	.0131	Dichlorprop	.0693
Atrazine	.0063	Dinitramine	.0193
Atrazine	.0064	Dinitramine	.0193
Atrazine	.0133	Diuron	.0064
Atrazine	.0149	Diuron	.0072
Benefin	.0053	EPTC	.0220
	.0077	EPTC	.0248
Benefin	.0077	Fluchloralin	.0070
	.0070	Fluchloralin	.0045
Bifenox	.142	Isopropalin	.0023
Butralin	.0128	Isopropalin	.0036
Butralin	.0077		.0054
Cyanazine	.0064		.0040
Di-Allate	.0138	Isopropalin	.0304
Di-Allate	.0248	Isopropalin	.0214
Di-Allate	.0180	Isopropalin	.0275
Di-Allate	.0110	Karbutilate	.0057
Dicamba	.0197		.0282
Dicamba	.2140	Karbutilate	.0118
Dicamba	>.2140	Linuron	.0104
Dicamba	.0486		.0231
Dicamba	.0902	Linuron	.0047
Dicamba	.0217	Linuron	.0280
Dicamba	.0407	Linuron	.0039
Dicamba	.0267	Linuron	.0061
2,4-D	.1733	MCPA	.1221
2,4-D acid	>.0768	MCPA	.1070
2,4-D	.1386	Metribuzin	.0298
2,4-D salt	.0768	Metobromuron	.0231
2,4-D	.1733	Metobromuron	.0248
2,4-D ester	>.0768	Monolinuron	.00216
2,4-D isooctyl ester	.2546	Monuron	.0060
2,4-D	.2731		
2,4-D amine	.1457		
2,4-D amine	.1008		

(continued)

TABLE B-6 (continued)

Pesticide	k_s	Pesticide	k_s
	HERBICIDES		
Monuron	0.0075	Silvex	0.0330
Neburon	.0073	Silvex	.0495
Neburon	.0059	Silvex	.0462
Nitralin	.0062	Simazine	.0074
	.0086	Simazine	.0083
Nitralin	.0096	Simazine	.0116
	.0086	Simazine	.0082
Nitralin	.0110	Simazine	.0539
Nitralin	.0079	Simazine	.062
Nitralin	.0090	Simazine	.0187
Nitralin	.0024	Tebuthiuron	.0024
Nitralin	.0155	Tebuthiuron	.0060
Nitralin	.0091	Tebuthiuron	.0427
Oryzalin	.0054-.0083	Tebuthiuron	.0201
Oryzalin	.0144-.0056	Tebuthiuron	.0517
Pebulate	.0396	Tebuthiuron	.0624
Pebulate	.0396	Tebuthiuron	.0069
Picloram	.0025	Triallate	.0090
	.0083	Triallate	.0110
	.0056	Triallate	.0144
Pebulate	.0396	Triallate	.0067
Pebulate	.0396	Triallate	.0088
Picloram	.0025	Triallate	.0053
Picloram	.00772	2,4,5-T	.0289
Picloram	.0044	2,4,5-T	.0330
Picloram	.0050	2,4,5-T	.0330
Picloram	.0354	2,4,5-T	.0508
Picloram	.0258	2,4,5-T	.0495
Picloram	.0268	2,4,5-T	.0416
Picloram	.0269	2,4,5-T	.0414
Picloram	.004	Trifluralin	.0037
Picloram	.0019	Trifluralin	.0047
Picloram	.0048	Trifluralin	.0051
Picloram	.0028	Trifluralin	.0044
Profluralin	.0047	Trifluralin	.0175
Profluralin	.0051	Trifluralin	.0956
Pometryne	.0238	Trifluralin	.0189
Propazine	.0108	Trifluralin	.0145
Propazine	.0056	Trifluralin	.0117
Propyzamide	.0061-.0158	Trifluralin	.0104

(continued)

TABLE B-6 (continued)

Pesticide	k_s
HERBICIDES	
Trifluralin	0.0026
Trifluralin	.0155
Trifluralin	.0091
Vernolate	.0396
Vernolate	.0396
INSECTICIDES	
Aldicarb	0.00273
Aldicarb	.0087
Aldicarb	.0991
Aldicarb	.0420
Aldicarb	.0322
Aldrin	<.0032
Aldrin	.0264
Aldrin	.0259
Aldrin	.0014
Aldrin	.0136
Aldrin	.0256
Aldrin	.0258
Aldrin	.0066
Aldrin	.0101
Aldrin	.0136
Aldrin	.0149 $\bar{x}$ of 19
Aldrin	.0165 $\bar{x}$ of 19
Aldrin	.0061
Aldrin	.0096
Aldrin	.0038
Aldrin (Dieldrin)	.0006
Aldrin (Dieldrin)	.0008
Aldrin (Dieldrin)	.0012
Aldrin (Dieldrin)	.0017
Akton	.0032
Azinphosmethyl	.0239
Azinphosmethyl	.0026
Azinphosmethyl	.0014
Azinphosmethyl	.0533
Azinphosmethyl	.0273
INSECTICIDES	
Azinphosmethyl	0.0516
Azinphosmethyl	.0086
Azinphosmethyl	.0119
Azinphosmethyl	.0235
Azinphosmethyl	.0074
Azinphosmethyl	.0101
Azinphosmethyl	.0458
Azinphosmethyl	.0505
Azinphosmethyl	.0211
BHC	.0021
BHC	.0140 $\bar{x}$ of 19
BHC	.0098 $\bar{x}$ of 19
BHC alpha	.0006
BHC beta	.00015
BHC gamma	.00042
BHC delta	.00036
Bromophos	.0198
Carbaryl	.0768
Carbaryl	.1196 $\bar{x}$ of 8
Carbaryl	.0969 $\bar{x}$ of 8
Carbofuran	.0768
Carbofuran	.0079
CGA-12223	.0385
CGA-12223	.0693
Chlordane	.00072
Chlordane	.0020
Chlorfenvinphos	.0055
Diazinon	.0330
Diazinon	.0151
Diazinon	.0067
Diazinon	.0242
Diazinon	.0239
Diazinon	.0239
Diazinon	.0248
Diazinon	.0189
Diazinon	.0260
Diazinon	.0166
Diazinon	.0171
Dieldrin	.0142
Dieldrin	.0187
Dieldrin	.0003

(continued)

TABLE B-6 (continued)

Pesticide	k_s	Pesticide	k_s
INSECTIDES			
Dieldrin	0.0002	Heptachlor	.0021
Dieldrin	.0001	Heptachlor	.0025
Dieldrin	.0008	Heptachlor	.0028
Dioxacarb	.0248	Hexachlorobenzene	.0006
Dioxacarb	.3465	Isobenzan	.0050
Dioxathion	.0156	Lindane	.0022
Dioxathion	.0128	Lindane	.0026
Dioxathion	.0141	Lindane	.0017
Dioxathion	.0229	Lindane	.0046
p,p'-DDT	.0008	Lindane	.0011
p,p'-DDT	.0005	Lindane	.0014
p,p'-DDT	.0021	Lindane	.0048
p,p'-DDT	.0014	Lindane	.0147
p,p'-DDT	.0009	Lindane	.0264
p,p'-DDT	.0004	Lindane	.0074
p,p'-DDT	.0009	Lindane	.0263
p,p'-DDT	.0037	Lindane	.0264
p,p'-DDT	.0024	Lindane	.0139
p,p'-DDT	.0048	Lindane	.0059
p,p'-DDT	.0003	Malathion	2.9173
p,p'-DDT	.0002	Malathion	2.4618
p,p'-DDT	.0011	Malathion	1.2681
p,p'-DDT	.0029	Malathion	.4152
p,p'-DDT	.00016	Malathion	1.9832
p,p'-DDT	.0007	Malathion	1.9026
p,p'-DDT	.00029	Mecarbam	.0495
Dimethoate	.0990	Methidathion	.0108
Disulfoton	.1604	Methidathion	.0495
Ednosulfan	.0162	Methoxychlor	.0046
Ethion	.0014	Methoxychlor	.0033
Ethion	.0012	Methyl Parathion	.2207
Ethion	.0009	Mevinphos	.2936
Ethion	.0015	Parathion	.0248
Ethion	.0014	Parathion	.056
Ethion	.0015	Parathion	.0046
Ethion	.0009	Parathion	.1239
Ethion	.0022	Parathion	$\bar{x}$ of 8 .0727
Ethion	.0032	Parathion	$\bar{x}$ of 7 .1371
Ethion	.0025	Parathion	.1306
Fenitrothion	.0578	Parathion	.0944
Fenitrothion	.1155		
Fonofos	.0158		

(continued)

TABLE B-6 (continued)

Pesticide	k_s
INSECTIDES	
Parathion	0.1150
Parathion	.0866
Parathion	.0654
Parathion	.0891
Parathion	.2962
Parathion	.2614
Phenthoate	.2865
Phenthoate	.0156
Phenthoate	.0141
Phorate	.0229
Phorate	.0040
Phorate	.0043
Phorate	.0051
Phorate	.0363
Phorate	.0078
Zinophos	.0277
Zinothos	.0223
Zinophos	.0164
Zinophos	.0144
Zinophos	.0244
Zinophos	.0096
Zinophos	.0133
Zinophos	.0206
Zinophos	.0075

Source: Nash (1980)

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